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[621 .131.3 (.493) & 621 .132.3 (.493)]

Results of tests on a four cylinder 4-6-2 locomotive, class 10, of the Belgian State, (1)

By F. LEGEIN,
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Figs. 1 to 4, pp. 665 to 670.

The Belgian State has, as an experiment, made a few alterations to one of the 4-6-2 locomotives, class 10, which have four equal cylinders, a working pressure of 14 kgr. (199.13 lb.) and a deep firebox of a grate area of 5 m² (53.82 square feet).

This engine, which was built in 1910, has already been described (2), so we will confine ourselves to giving the principal dimensions.

Diameter of coupled wheels		1 980 mm. (6 ft. 6 in.).
Four equal cylinders.	Diameter	500 mm. (19 11/16 inches).
	Stroke	660 mm. (26 inches).
Working pressure		14 kgr./cm² (199.13 lb. per sq. in.).
Diameter of boiler barrel (2nd ring)		1 800 mm. (5 ft. 10 7/8 in.).
Large tubes.	Number	31.
	Diameter	118/127 mm. ($4\ ^5/_8$/5 inches).
Small tubes.	Number	230.
	Diameter	45/50 mm. ($1\ ^{25}/_{32}$/$1\ ^{31}/_{32}$ in.).
Length of tubes between tube-plates		5 000 mm. (16 ft. 4 7/8 in.).
Diameter of superheater tubes.		27/34 mm. ($1\ ^1/_{16}$/$1\ ^{11}/_{32}$ in.).
Grate area		5 m² (53.82 sq. feet).
Weight in working order		111.4 t. (109.64 English tons).

In view of their ample adhesive weight and boiler capacity, these engines have done very good work in hauling express passenger trains over heavy roads,

(1) Translated from the French.

(2) See : *The Belgian State Railways stock at the International Exhibition at Brussels 1910*, by J. B. Flamme, published in 1911 in Paris, by H. Dunod and E. Pinat, actually 92, rue Bonaparte of which a review appeared in the July 1911 number, p. 845, of the *Bulletin of the Railway Congress*.

See also an article intitled : « Railway rolling stock at the Brussels Exhibition 1910, by A. Schubert », in the January and February 1911 numbers of the *Revue générale des chemins de fer*.

especially between Brussels and Arlon where there are numerous long inclines of 1 in 62, and for which the loading of this particular class of engine is fixed at 360 t. (354.31 English tons), and between Brussels and Liege which is on an almost continuous incline of 1 in 333 to 1 in 200.

This type of engine, however, had some weak points, which are also met with on a number of powerful locomotives built about the same time :

1) The superheat was insufficient, the temperature of the steam scarcely exceeding 300° C. (572° F.);

2) The superheater afforded an insufficient cross area for the flow of steam to the cylinders; the drop of pressure between the boiler and the steam chest being about 2 kgr. per square centimetre (28.44 lb. per square inch) when working at full power;

3) The back pressure during exhaust when working heavily was too high, being as much as 0.8 or 0.9 kgr. per square centimetre (11.38 to 12.80 lb. per square inch).

The alterations which have been introduced in order to overcome these disadvantages have consisted in the fitting of a new superheater and of a different exhaust arrangement.

New superheater. — The original tubeplate contained 31 large flue tubes of 118/127 mm. (4 $^{5}/_{8}$/5 inches) and 230 ordinary tubes of 45/50 mm. (1 $^{25}/_{32}$/1 $^{31}/_{32}$ inches). The length between tubeplates was 5 m. (16 ft. 5 in.). The superheater consisted of 31 elements, double loop of 27/34 mm. (1 $^{1}/_{16}$/1 $^{11}/_{32}$ inches). The distance from the end of the elements to the firebox tubeplate was 610 mm. (2 feet). As has been said above, the temperature of the steam hardly exceeded 300° C. (572° F.), which is insufficient for economical working. It may be mentioned that at the time when this class of engine was built it was a rule to make the superheater heating surface a certain proportion of the ordinary heating surface. This method is incorrect as it is based on the supposition that the average efficiency of the heating surface and of the superheater heating surface are fixed quantities, whereas this is far from being the case; the transference of heat through a superheater element decreases rapidly as the distance from the firebox increases, so that it is practically zero at the smokebox end. The efficiency of the ordinary tubes also decreases, but much less rapidly towards the smokebox end. Finally what is also very important, the rate of heat transference depends upon the speed of circulation of the gas. It is not sufficient therefore that the superheater should present a suitable and well situated surface, but it is necessary that this surface shall come in contact with a sufficiently great proportion of the total products of combustion. It is obvious that this proportion should also increase when the evaporation per kilogram of fuel is increased.

The new superheater consists of 40 elements in flue tubes 125/133 mm. (4 $^{59}/_{64}$/5 $^{15}/_{64}$ inches) diameter. The number of ordinary small tubes 45/50 mm. (1 $^{25}/_{32}$/1 $^{31}/_{32}$ inches) diameter has been reduced to 190. The elements consist of tubes 30.5/38 mm. (1 $^{13}/_{64}$/1 $^{1}/_{2}$ inches) diameter; moreover, the return loop no longer extends to the smokebox tubeplate, but stops at a distance of 3.60 m. (11 ft. $^{47}/_{64}$) from the firebox tubeplate. In agreement with the general modern practice, the superheater dampers have been aban-

doned. The four air valves which are placed on the steam pipes leading to the cylinders have been replaced by one specially designed air valve which is placed on the saturated side of the heater (fig. 1). This air valve is constructed on the lines

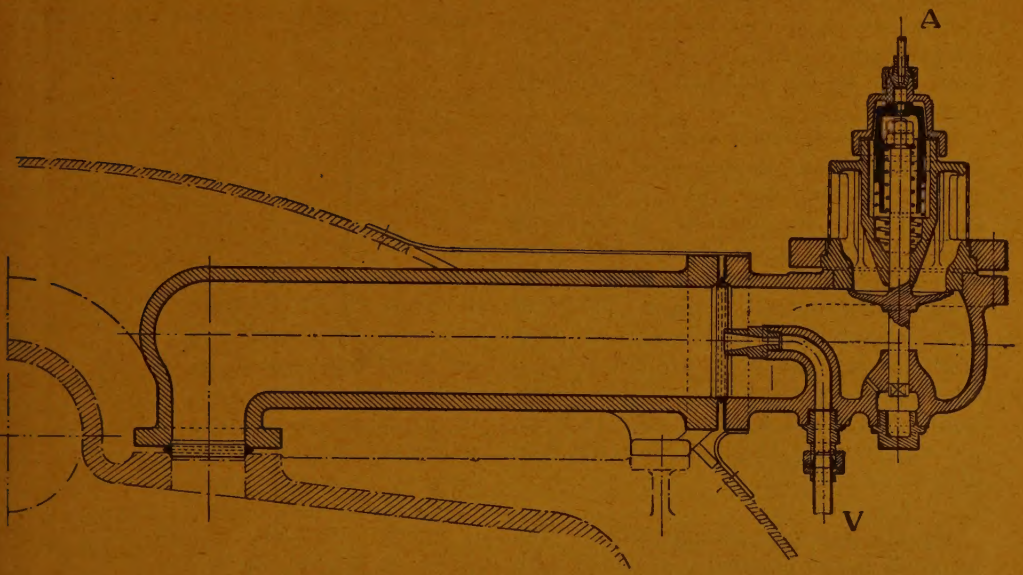

Fig. 1.

of the Knorr valve operated by compressed air. In the pipe connecting the air valve to the superheater header is a jet of steam introduced at V which increases the amount of air drawn in through the air valve. The supply of steam is controlled by a cock placed on the smokebox (see fig. 3) and operated from the cab by means of a rod carried along the side of the boiler. This cock remains open as long as the engine is running whether the regulator is shut or open.

When the regulator is shut, the driver operates the valves controlling the cylinder bye-passes. He does this by operating the three-way cock placed in a convenient position in the cab which supplies compressed air to the cylinders operating the bye-pass valves. Compressed air is at the same time introduced through pipe A (fig. 1) to the air valve placed on the header. This opens and air is drawn in from the atmosphere by the cylinders which passes through the superheater, cools the elements and is warmed before passing into the cylinders. The steam jet, which is mentioned above, increases the flow of air, and this steam has also a favourable effect on the lubrication of the cylinders.

This arrangement has given very good results; the engine runs freely with the regulator closed, and the lubrication of the piston valves is very satisfactory. These advantages are obtained at the cost of a comparatively small amount of steam. When running with the regulator

open, the steam from the jet merely mixes with steam coming from the regulator and is therefore used in the cylinders in the ordinary manner.

The new type of superheater allows temperatures of 345 tot 350° C. (653 to 662° F.) to be obtained in ordinary running.

The inside diameter of the tubes forming the elements having been increased from 27 to 30.5 mm. (1 $^{1}/_{16}$ to 1 $^{13}/_{64}$ inches) and the number of elements being 40 instead of 31, the total free area offered to the steam is now 292.2 cm² (45.29 square inches) as against 177.5 cm² (27.51 square inches). The drop of pressure between the boiler and the steam chest is now within reasonable limits and is less that 1 kgr. per cm² (14.22 lb. per square inch) under the heaviest conditions of working.

Double blast pipe arrangement. — The locomotive was originally provided with a simple blast arrangement, the blast pipe orifice being 260 mm. (10 $^{1}/_{4}$ inches) above the centre line of the boiler. The relative position of the blast pipe and chimney is shown in figure 2.

This arrangement was not altogether satisfactory for an engine with a deep firebox having 5 m² (53.82 square feet) of grate area. This may be easily realised from the fact that a chimney of the same diameter is used on engines of half the capacity.

If the chimney of the class 10 locomotive had to discharge twice the amount of steam and products of combustion, the velocity of the steam and products would require to be twice as great. To double the velocity of the steam requires *four times* the amount of back pressure. This is on the supposition that the diameter of both the chimney and of the blast pipe orifice remain the same.

Actually, this is not the case, the diameter of the blast pipe orifice being 150 mm. (5 $^{29}/_{32}$ inches) in the class 10 locomotives, while it is 135 mm. (5 $^{5}/_{16}$ inches) in engines of half the capacity.

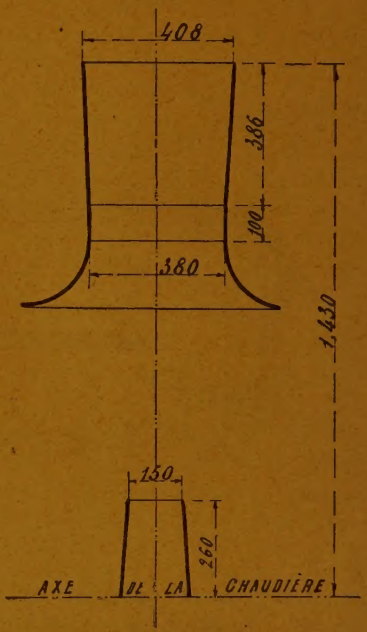

Fig. 2.

Explanation of French terms :
Axe de la chaudière = Centre line of boiler.

This increase in the diameter of the blast pipe top reduced the amount of back pressure, but this advantage was obtained at the price of another disadvantage. The ratio of the respective diameters of chimney and blast pipe is diminished, and for this reason the efficiency of the exhaust arrangement is reduced and the quantity of products of combustion which may be entrained by each kilogram of steam was reduced. That was evidently the reason why the diameter 150 mm. (5 $^{29}/_{32}$ inches) for the single blast pipe of the class 10 engine could

not be increased. The difficulty could only be overcome by using fuel of good quality and being content with a low temperature of superheat.

To overcome these difficulties, it was desirable to use a chimney of very much greater diameter and a blast pipe orifice increased proportionately. It appeared necessary to adopt areas for the chimney and blast pipe twice those on existing satisfactory engines of half capacity.

One would have had therefore to increase the distance between the blast pipe and the chimney in the ratio of $\sqrt{2} = 1.41$. It is necessary to be sure that the jet of steam will just touch the top of the chimney. The angle of the steam jet being constant and about 1 in 10, it is therefore clear that as the areas are increased, the distance between the blast pipe and the chimney must be increased.

If the available space allowed this to be done, it would be simpler to design a single blast pipe and chimney which would satisfy the required conditions. Although this can be done very well for engines with grate areas of from 2 to 3 m² (21.5 to 32.3 square feet) (with deep fireboxes) it is not so easy in cases where the grate is 5 m² (53.82 square feet) or over.

In the particular case of the class 10 engines, it was necessary to keep within the loading gauge of 4.28 m. (14 ft. 1/2 in.) and to place the blast pipe at a suitable distance above the inside cylinders.

It appeared worth while to try the effect of a double arrangement of blast pipe and chimney, which simply consisted of using side by side two simple blast arrangements each of half the area which would be necessary with a single blast pipe.

This idea was not new, Nozo and Geoffroy have suggested this, and have referred to devices of this kind in their very remarkable paper which was presented to the Society of French Civil Engineers in 1863, a very valuable article in which these two capable engineers laid down in a very clear and precise manner the principle of the locomotive exhaust.

At that time locomotives were far less powerful than they are today, and it was very easy to obtain the correct proportions of the blast pipe and chimney without fouling the loading gauge. A double blast arrangement, although proved to be practicable, had no reason for its application, and therefore the results of the tests of this kind carried out by Nozo and Geoffroy have never been applied in practice to locomotives.

But conditions of locomotive construction have very greatly changed since then. On the one hand the loading gauge remains the same, while on the other hand the use of inside cylinders of ever increasing diameter had led to the height of the blast pipe being raised rather than lowered. The distance between the blast pipe orifice and the top of the chimney has therefore decreased, whereas this height should, strictly speaking, be increased approximately in the ratio of the square root of the weight of the steam produced.

Figure 3 shows the application of a double blast to locomotives of class 10. It may be pointed out that the two blast pipes branch out from a *common* connection and that each of the two cylindrical chimneys communicates direct with the one smokebox. The diameter of each of the blast pipe orifices is 135 mm. ($5\ ^{5}/_{16}$ inches). They are therefore equivalent to a single orifice of 191 mm. ($7\ ^{33}/_{64}$ inches) diameter which must be compared with a diameter of

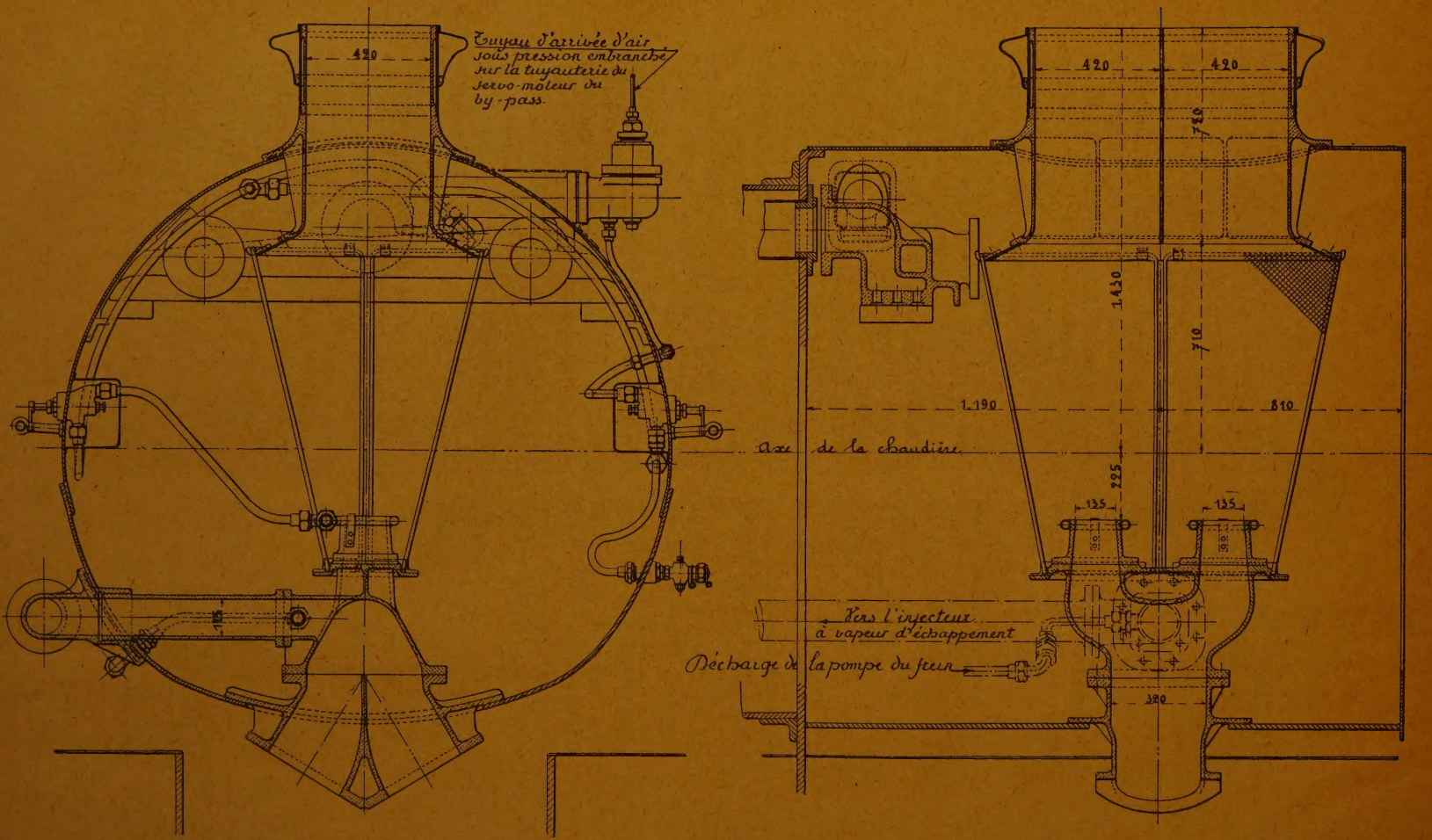

Fig. 3.

Explanation of French terms: Tuyau d'arrivée d'air sous pression embranché sur la tuyauterie du servo-moteur du by-pass = Incoming compressed air pipe connected to pipe arrangement of by-pass servo-motor. — Axe de la chaudière = Centre line of boiler. — Vers l'injecteur à vapeur d'échappement — To exhaust steam injector. — Décharge de la pompe du frein = Brake pump exhaust.

150 mm. (5 $^{29}/_{32}$ inches) of the single blast pipe of class 10 locomotives. The total area of discharge is therefore 1.62 times greater.

The ratio of the diameter of the chimney to the diameter of the blast pipe orifice which was originally $\frac{408}{150} = 2.72$ is now equal to $\frac{420}{135} = 3.11$.

The increase of this ratio improves the efficiency of the blast, the weight of gas entrained per kilogram of steam being increased.

This double blast arrangement has given every satisfaction and allows the boiler to work up to its maximum capacity, that is, more than 15 000 kgr. (33 000 lb.) of steam per hour with a blast pipe orifice having an area 1.62 times greater than that formerly used, although the steam is raised to a higher degree of superheat, which should justify a smaller blast pipe orifice.

Results obtained during dynamometer tests have shown that the back pressure, which in some cases was as great as 0.95 kgr. per square centimetre (13.51 lb. per square inch) with the single blast pipe, does not exceed 0.37 kgr. per square centimetre (5.26 lb. per square inch) with the double blast pipe when working under similar conditions (1).

* * *

Dynamometer tests. — Engine No. 4505, class 10, was submitted to a series of dynamometer tests; it was fitted with the new design of superheater described above, double blast arrangement and Metcalfe exhaust steam injector.

(1) With a cut off of 45 %, regulator full open at a speed of 66 km. (41 miles) per hour.

The principal results of the trial are given below :

First trip : Brussels-Nord to Ans (Liége), train No. 82, 6 July 1925.

Number of axles in train...	60 (maximum booked loading).
Number of vehicles.....	15 (bogies).
Total weight of train.....	725 t. (714 Engl. tons).
Total tare weight of train...	613 t. (603 —).

The line from Brussels-Nord to Ans, consisting of 94 km. (58.4 miles) of almost continuous up grades of from 1 in 330 tot 1 in 200, was covered in 74 m. 55 s. without a stop. The maximum steaming capacity of the boiler was not reached, while the running speed was limited at a number of places by reason of permanent way slacks.

The results obtained by the dynamometer car for this trip were as follows :

Total work, in indicated horse-power hours.	T_i	= 2 050
Drawbar horse-power hours . .	T_u	= 1 265
$\frac{\text{D. H. P. hours}}{\text{I. H. P. hours}}$	$\frac{T_u}{T_i}$	= 0.618
Total water consumed.	E	= 17 000 litres (3 740 English gallons).
Total coal consumption	C	= 2 250 kgr. (4 960 lb.).
Average steam consumption, in kilograms (in lb.) per indicated horse-power hour.	$\frac{E}{T_i}$	= 8.30 (18.30 lb.).
Average coal consumption, in kilograms (in lb.) per indicated horse-power hour.	$\frac{C}{T_i}$	= 1.098 (2.42 lb.).

Second trip : Brussels-Nord to Arlon, train No. 14, 11 July 1925.

Number of axles in train...	36
Number of vehicles.....	9
Total weight of train.....	384 t. (378 Engl. tons).
Total tare weight of train...	342 t. (337 —).

The line from Brussels-Nord to Arlon is an undulating one 192 km. (119 miles) long with gradients in many places as much as 1 in 62. The portion of line from Namur to Courriere is on an almost continuous up grade of 1 in 62 over

13 km. (8 miles); a speed of 60 km. (37.3 miles) per hour was maintained over this portion.

The results of the dynamometer tests were as follows :

Total work, in indicated horse-power hours	$T_i = 3\,480$
Drawbar horse-power hours	$T_u = 2\,165$
D. H. P. hours / I. H. P. hours	$\frac{T_u}{T_i} = 0.624$
Total water consumed	E = 32 220 litres (7 085 English gallons).
Total coal consumption	C = 3 872 kgr. (8 535 lb.).

Average steam consumption, in kilograms (in lb.) per indicated horse-power hour.	$\frac{E}{T_i} = 9.25$ (20.39 lb.).
Average coal consumption, in kilograms (in lb.) per indicated horse-power hour.	$\frac{C}{T_i} = 1.11$ (2.44 lb.).

The higher average consumption in the case of this test is caused by the less advantageous conditions under which the engine was working (long cut offs, lower speeds and more frequent closing of the regulator) which arises from the difficult gradients on the line.

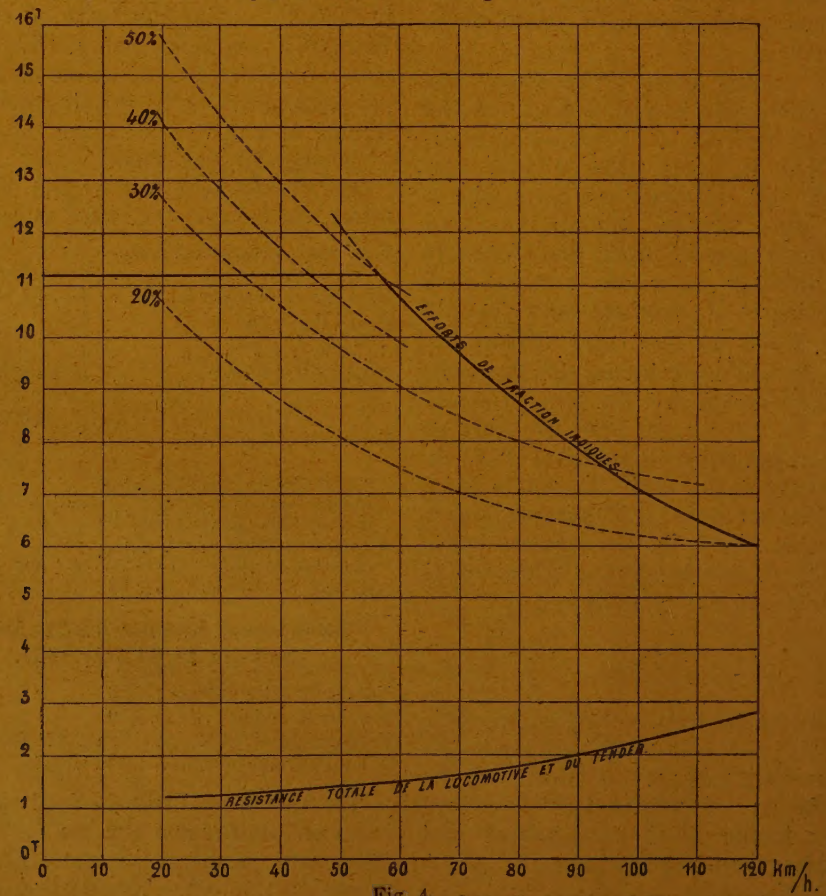

Fig. 4.

Explanation of French terms : Efforts de traction indiqués = Indicated tractive power. Résistance totale de la locomotive et du tender = Total resistance of locomotive and tender.

Third strip : Brussels-Nord to Ostend and return, with trains Nos. 3025 and 3042, 18 September 1925.

This trip was carried out solely to determine the curves representing the indicated tractive effort for various speeds and cut offs, the regulator being fully opened and a full boiler pressure of 14 kgr. per square centimetre (199.13 lb. per square inch) being maintained.

The curves are given on figure 4.

The diagram also gives the resistance of the engine and tender for various speeds.

The various tests carried out with this engine have shown that when a good class of fuel is used (brickets) the normal output in steady running is given by multiplicating the speed in kilometres per hour by the cut off in the cylinders expressed as a percentage, the product being equal to 2 400.

The diagram also shows a curve calculated on this basis giving the maximum sustained tractive efforts.

The maximum indicated horse-power, obtained during the tests is 2 700, at 20 % cut off and 120 km. (74.6 miles) per hour.

The total weight of engine and tender in working order being 111.4 t., the maximum horse-power developed per ton is 24.2, an extremely high figure.

The curves shown on figure 4 are those obtained with engine No. 4505. This engine, not being new, differs slightly as regards the diameter of wheels and cylinders from the original dimensions. The expression for the tractive effort $\frac{2pd^2l}{D}$ works out for this particular engine as 24 069, whereas the original dimensions give a figure of 23 333.

By using the actual dimensions d and D in the tractive effort formula :

$$T_i = \alpha \cdot \frac{2pd^2l}{D}$$

the various values of α being given by the following table :

Values of α in the formula $T_i = \alpha \cdot \frac{2pd^2l}{D}$.

n, number of revolutions per minute.	V, speed per hour		Cut off per cent :			
	in kilometres.	in miles.	20	30	40	50
60	22.38	13.91	0.4340	0.5150	0.5725	0.6360
80	29.82	18.53	0.4020	0.4810	0.5330	0.5920
100	37.30	23.18	0.3750	0.4495	0.4970	0.5500
120	44.75	27.81	0.3500	0.4220	0.4655	0.5120
140	52.20	32.44	0.3300	0.3980	0.4365	0.4820
160	59.62	37.05	0.3120	0.3770	0.4125	0.4555
180	67.10	41.70	0.2965	0.3582	...	...
200	74.60	46.36	0.2840	0.3430	...	...
220	82.00	50.95	0.2730	0.3282	...	...
240	89.50	55.61	0.2660	0.3180	...	...
260	97.00	60.27	0.2582	0.3082	...	...
280	104.50	64.92	0.2545	0.3022	...	...
300	111.80	69.47	0.2505	...	...	...
320	119.20	74.06	0.2490	...	...	...

* * *

The test taken as a whole led to the following conclusions :

The maximum indicated horse-power of engines of class 10 has been increased from 2 250 to 2 700, while the consumption per indicated horse-power hour has been reduced approximately 20 %.

These results are due :

a) to the considerable reduction in back pressure;

b) to the decrease in the drop of pressure between boiler and steam chest;

c) to the higher temperature of superheat.

The influence of the superheat has had the principal effect in the fuel economy which has been realised.

[625 .14 (.73)]

A design for permanent track construction,

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Figs. 1 to 4, pp. 675 and 676.

(*Railway Age.*)

The type of track now in use by the railroads was evolved very early in their history and has been retained ever since without essential change. To keep pace with the increase in the weight of equipment and the volume of traffic, heavier rails with stronger fastenings of improved pattern have been used, the depth of the ballast has been increased, and the ties have been placed closer together; but the general arrangement is still the same. On account of its adaptability to the varying conditions incident to the growth of the railway system, such as an unseasoned roadbed and frequent changes in line and grade, no other type of track could have served the purpose as well, on the score of either efficiency or economy.

But on most of the railroads in this country a different set of conditions is now encountered. Traffic routes have become fixed. Few changes of line or grade which involve any considerable mileage are contemplated. Embankments have become seasoned and, for the most part, show no further settlement. Wheel loads are approaching the maximum which is permissible, unless steel rails can be made both harder and tougher than at present. The increasing cost of ties is only partially offset by the longer life obtained by treatment. Suitable ballast is increasingly more expensive and track labor is becoming scarcer and, measured in performance, more costly.

A more permanent track is desirable.

Altered conditions in highway traffic were promptly met by the development of a new type of pavement. Likewise the street railways rapidly developed types of track structures which are well adapted to their peculiar conditions. The time has now arrived when careful consideration should be given by the railroads to the development of a type of track which is more suitable to present conditions on heavy traffic lines. Some pioneer work has been done along this line, both as to suggested design and actual construction, experimental or otherwise. Of the former, J. W. Schaub's contributions on the subject as long ago as 1907 are notable. (See *Railway Age* of 31 Mai 1907, page 835, and *Railroad Age Gazette* of 27 November 1908, p. 1431.) In 1919 A. C. Irwin described a number of such types of track in a paper before the American Concrete Institute. The principal cases of actual construction carried out up to the time of its publi-

cation are described in volume 21 of the *Proceedings of the American Railway Engineering Association* for 1920.

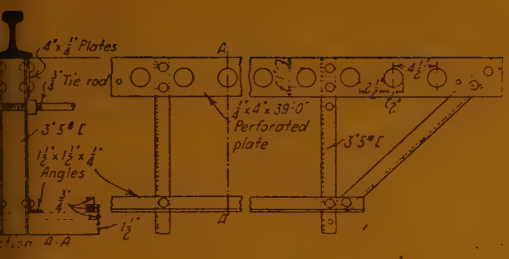
Such an installation, even on an experimental scale, is necessarily expensive; and before such expense is incurred it is desirable not only to profit by past experience, but also to consider such suggestions as may be offered by all who are interested. This article is written in the hope that the design of track herewith submitted and the estimate of the savings which would result from its use will stimulate interest in this matter and will bring forth constructive criticism which will not only result in the improvement of the design, but will also throw more light on the economic value of a track of this type. Comments on the part of those who have had experience in regard to track of the permanent type on either railroads or street railways will be especially welcome.

By permanent track is meant a track structure in which wear and deterioration are confined as far as possible to the rail. The requirements for such a track structure are most exacting, — so much so that in certain situations they cannot all be met with the design here submitted, although it is not unlikely that a type of structure can be developed which would meet even these severe requirements. Such conditions include fills that are not fully settled, fills over sink holes or over ground filled with water which may be removed subsequently by drainage, soils of such texture that freedom from heaving by frost cannot be secured by thorough drainage, and places where changes in connections with side tracks are frequent. However, on old lines these situations comprise only a small fraction of the total, and their existence need not interfere with the use of permanent track on the remainder, if such use is advantageous.

Such a structure must be wide enough and strong enough to distribute the load over such an area that the bearing power of the sub-grade will not be exceeded. Allowance must be made for impact, for lack of uniformity in the support given by the sub-grade, and for the present tendency toward heavier loading. Temperature stresses must be taken into consideration; and protection of the concrete under the rail from disintegration due to repeated shock from the passing loads seems desirable, although trial may prove this feature not to be essential.

The method of attaching the rail should permit of its easy placing and removal. Methods and type of construction must be such that the rail, when laid in its prepared place, will have perfect surface and alinement. However, the design should be such as to permit minor adjustment of elevation by shimming, as occasional slight settlement may be looked for even in seasoned fills, and changes in traffic conditions may make a change in the super-elevation of curves desirable. Ease of insulation is another feature that must not be overlooked. As there will be occasional situations where it will be desirable to retain the present type of track, any design should permit an easy and practicable connection of the two types of construction.

These features have all been considered in the design submitted herewith. The supporting slab of concrete is 10 feet wide and 18 inches thick. Assuming the use of 39-foot rails, the concrete would be cast in sections of that length. The rails rest ont the edges of two plates which are embedded in the concrete, and are perforated in order to provide better bond and more bearing on the concrete. These serve a fourfold purpose : 1) To distribute the load and impact over a greater area of concrete; 2) to protect the concrete from shock and possible disintegration due to direct contact with the rail; 3) to afford a means of attaching the rail; and 4) to insure a setting for the rail which is absolutely true as



ig. 1. — Typical details of the longitudinal frame.

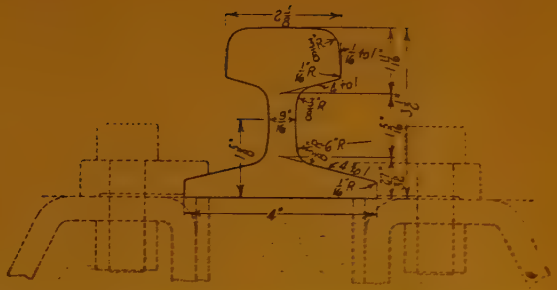
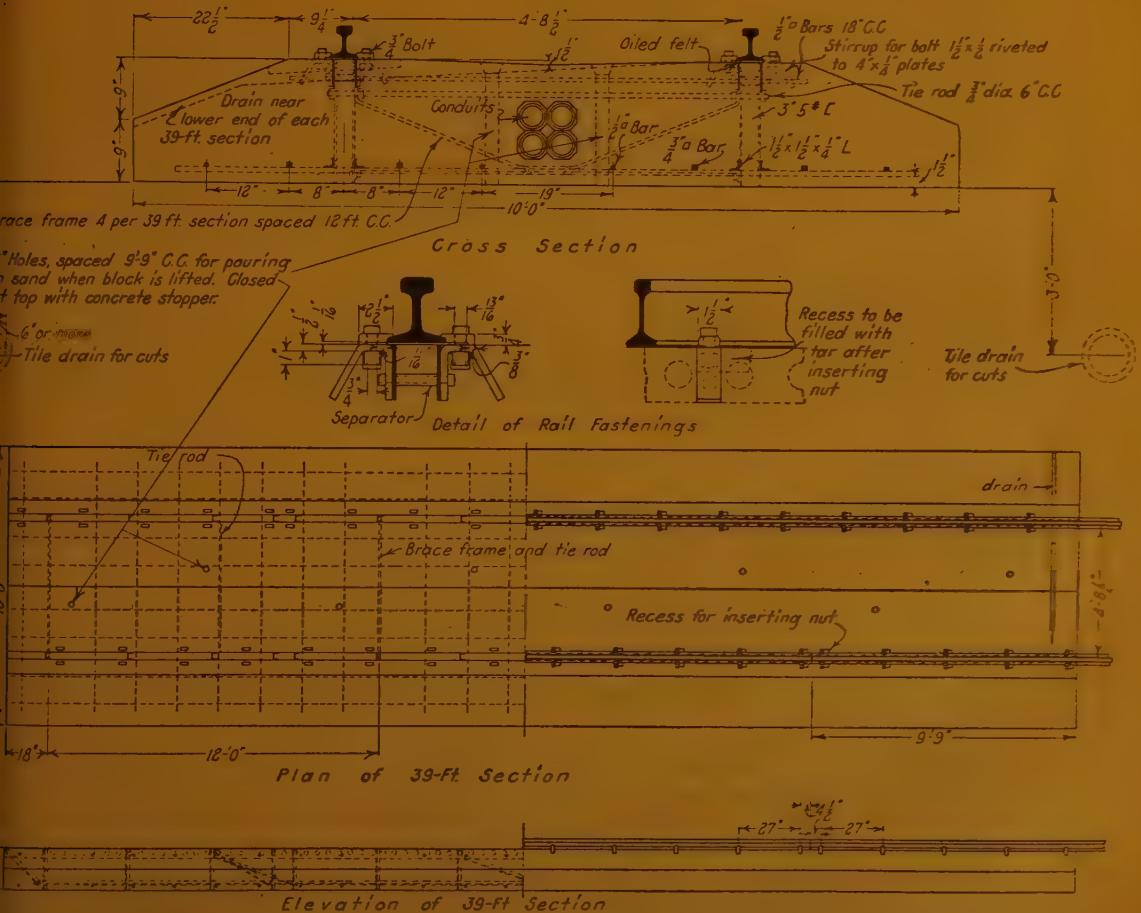


Fig. 2. — A suggested design of rail for use on concrete slabs.



ig. 3. — Proposed design of concrete track slab in which the rails rest on the top edges of the reinforcing frames.

to line and surface. In addition, they form a guide for striking off the concrete surface in finishing.

A truss reinforcement is employed.

The plates which form the rail seat also form the upper chord of a light truss, the lower chord of which serves as a part of the longitudinal reinforcement. The vertical members of this truss serve to anchor the rail seat to the concrete, and are extended below the lower chord, so that they may rest upon stakes driven accurately to the elevation of the sub-grade. This truss would be shop-made, and the bracing and riveting need only be of sufficient strength to prevent distortion while handling. When set in place, these trusses are connected by adjustable tie rods spaced 6 feet apart, and also by the brace frames shown on the drawing. Four of these brace frames are used for each 39 foot section. One of the tie rods forms the upper member of the brace frame. This arrangement gives a rigid framework which can be set accurately in place and will remain undisturbed while the concrete is being placed. It will also serve to transmit the loads into the mass of concrete.

Longitudinal reinforcement consists of four 3/4 inch bars and four 1/2 inch bars in addition to the two 1 1/2 inch by 1 1/2 inch by 1/4 inch angles which constitute the lower members of the trusses. The ratio of longitudinal reinforcing metal is about 0.37 %. Assuming a Cooper E-70 loading concentrated under the axle, with 50 % allowance for impact and uniform bearing on the sub-grade, the tensile stress in the steel would be about 9 000 lb. per square inch and the compressive stress in concrete would be about 200 lb. per square inch.

Transverse reinforcement consists of 3/4 inch square bars spaced 18 inches center to center near the base of the slab, and 1/2 inch square bars spaced 18 inches center to center near the top of the slab. Where brace frames and tie rods occur, other transverse reinforcement is omitted. Assuming the 70 000 lb. on a pair of drivers to be uniformly distributed over a longitudinal distance of 5 feet, and again assuming an impact allowance of 50 % and that the upward pressure of the sub-grade is uniformly distributed, we obtain a unit tensile stress of 14 000 lb. for the steel and a unit compressive stress of about 300 lb. for the concrete.

Fig. 4. — Alternative design in which the rail is supported on a pair of angles.

These unit stresses are ample to take care of any increase in future loads, impact and unequal subgrade conditions. On account of the greater length of the section as compared with its width and the consequent opportunity for more variability in the condition of the subgrade it is thought desirable to use a much lower unit stress for the longitudinal reinforcement than for the transverse. With modern methods of proportioning and making concrete the maximum of economy may be obtained through designing the concrete to meet the actual condition of stresses disclosed through experience in the use of this type of

roadbed. It might seem that some economy in design could be attained by not using so thick a slab and using a higher percentage of reinforcement. On account of the impact however, it is believed that the additional mass obtained by using a greater thickness is well worth its additional cost.

In order to facilitate construction the concrete slab should be poured continuously, and not in alternate sections. A metal separator would be placed at the end of the section being poured. After the adjoining section had also been poured this separator would be removed. It is not planned to leave any well-defined joints between the sections, on the assumption that compression due to high temperature would easily be taken care of by the concrete, the thickness of which would prevent any tendency to buckle; and that tensile stresses would cause a cleavage at the end of each section, inasmuch as none of the longitudinal metal is continuous. When these joints develop, they should be filled with tar, as is now done with concrete highways. In construction, the removal of the separator would be delayed until at least a portion of the block ahead of it was poured, thus giving the block behind it a start toward setting and insuring a cleavage practically along the plane of the separator.

The rail is held by rail-clips, which are attached by bolts to stirrups bolted to the perforated plates and embedded in the concrete. The bolt is placed with the head up and screwed into a nut which is inserted beneath the stirrup through a recess provided for that purpose. This recess is only slightly wider than the nut, thus preventing it from turning. This arrangement tends to lessen the danger of injury to the bolts in case of derailment, and permits their replacement if injury should occur, or the substitution of a longer bolt in case slight shimming is desirable. Nutlocks can be used under the bolt head if desired. No angle bars or fish plates are necessary, as the rail seat and rail attachments serve their purpose.

Secondary considerations.

With such a design, the rail no longer functions as a beam. A wearing surface and a base for bearing and attachment are all that need be provided, so that a much lighter rail may be used than at present. A suggested design for a 60-lb. rail is therefore shown, which it is believed would be fully as effective as a 130-lb. rail under present conditions.

Rail anchors would not be needed. It is possible that creeping of rail could be avoided by keeping the bolts near the center of the rail tighter than those at the end. If this did not prove satisfactory, the rail could be anchored by one or two bolts near its middle point, thus insuring the expansion and contraction of each rail as a separate unit. If it should prove desirable which does not appear probable, to give a slight cushioning effect and lessen the impact on the concrete, it is believed that a thin layer of oiled felt beneath the rail would be effective. This felt should be treated with some bituminous mixture in order to preserve it. This mixture should not contain too much tar or asphalt, so that it will not become brittle and break up in cold weather. Perhaps a treatment with crude petroleum would be satisfactory. A layer of felt about 1/8 inch thick, compressing to a thickness of 1/16 inch under the tightening of bolts which hold the rail, and further compressing to perhaps one-half this thickness under an engine load, would probably go far toward reducing the shock upon the concrete beneath the rail-seat. It would also lessen the noise. Insulation between any two sections of track could be accomplished by substituting insulating fiber for the felt. This insulation should extend from the rail joint to the end of the concrete block.

Thorough drainage is essential. On fills made of sand no artificial drainage would be necessary, but on other fills it should be taken care of by tile drains just beyond the edges of the slab, with frequent outlets to the side of the embankment. In cuts the drains should be placed deeper and under the cut ditches, in order to prevent ground water from reaching the track. The proper functioning of these drains is a very important matter and they should be of ample size and have good outlet facilities.

Conduits for carrying all wiring, such as telegraph, telephone, block signals and train control, can be placed in the center of the slab as shown in the cross section, or can be placed elsewhere in the section if desired.

It is not likely that such construction as here proposed would be used to any considerable extent on single track, as its cost would not, in general, be justified by the amount of traffic. Further, to build it on a single track railroad would necessitate the construction of a temporary track to carry traffic around the section of roadbed under improvement. This feature calls for the consideration of pre-cast slabs, to be inserted under traffic. This would seem to be entirely feasible, but it is not likely that as uniform a bearing on the subgrade could be had as if the concrete were moulded in place, which might result in a slight inequality of settlement of the pre-cast sections.

On double track, however, traffic could be diverted to the track not being improved, without undue expense or serious interruption of traffic. Under such conditions it is probable that the pre-cast section would be more expensive, even taking into account the expense due to traffic interference. It is quite possible however, that in certain situations this would not be the case and the pre-cast method would be more desirable.

An estimate of the cost.

The cost of roadbed of this type will vary with the conditions existing at each installation, such as the cost of materials and labor, and the amount of traffic. The following is an estimate of the cost under average conditions, based on the assumption that the railroad company would purchase and deliver all materials and handle the diversion of traffic and that the labor of placing the concrete, including unloading materials, would be done by contract.

Estimated cost per mile of track with a concrete base			
Material, furnished by railroad company			
Rail and fastenings			
70-lb. rail, 110 tons	@$43.00	$4 730	
5 000 rail clips, 3 200 lb.	@ 0.06	192	
5 000 bolts and nuts, 4 000 lb.	@ 0.04	160	
Transportation and storeyard expense, 114 tons	@ 2.00	228	
Total rail and fastenings			$5 310
Concrete base, 18 inches thick, 0.5 cubic yard per lineal foot			
Proportions 1 : 2 : 4			
Stone or washed gravel, 2 400 cubic yards	@ 1.00	2 400	
Sand, 1 200 cubic yards	@ 0.75	900	
Cement, 4 225 bbl.	@ 2.20	9 295	
Structural steel, 176 000 lb.	@ 0.045	7 920	
Reinforcing bars, 105 000 lb.	@ 0.03	3 150	

Transportation (by carrier) 6 400 tons, 100 miles @$0 007 per ton mile		4 480		
Drain tile, 5 280 lineal feet	@ 0.10	528		
Felt, 2 000 square feet	@ 0.06	120		
Total for concrete base.			28 793	
Total material			$34 103	
Labor, by contract				
Removing old track		500		
Levelling ballast for sub-grade		500		
Laying tile drain, 5 280 lineal feet	@ 0.10	528		
Unloading materials, mixing, placing concrete and steel, 2 640 cubic yards	@ 3.25	8 580		
Laying rail		750		
Total contract labor			10 858	
Engineering.			800	
Diverting traffic.			3 000	
Total per mile				$48 761
Estimated cost per mile of rail and accessories in present track that would be retired				
100 lb. rail, 157.14 tons	@ 43.00	6 757		
Angle bars, 320 pair, 22 400 lb.	@ 0.03	672		
Bolts, 1 280, 2 900 lb.	@ 0.04	116		
Spikes, 12 000, 7 000 lb.	@ 2.00	196		
Tie plates, 6 000	@ 0.25	1 500		
Rail anchors, 1 000	@ 0.25	250		
Transportation and store yard expense, 200 tons.	@ $2.00	400		
Labor installing		900		
Total per mile		$10 791		
Net cost per mile of track with concrete base				$37 970

The anticipated savings.

The advantages that would result from a permanent track may be classified as follows :

1. Reduction in the cost of maintenance of way :
   - *a*) Ties, eliminated;
   - *b*) Ballast, eliminated;
   - *c*) Track labor, reduced to rail renewals and track walking;
   - *d*) Probably reduced wear on rails and angle bars.
2. Reduction in the cost of maintenance of equipment.
3. Reduction in train resistance, resulting in :
   - *a*) Less fuel consumed;
   - *b*) Greater tonnage per train, with fewer trains; or higher speed, with less train hours.
4. Greater safety, especially at high speeds.
5. More comfort for passengers, due to smoother riding and freedom from dust.
6. Advertising value to the early users.

The last three items have a value that is very real, although so intangible that it is obviously impossible to estimate it in money. This value would be great for roads having a large volume of high speed passenger business. The passenger traffic of today demands the highest speed compatible with safety, and the

same is true of certain classes of freight. In general, track conditions are now the controlling factor in limiting speed. With a track in perfect line and surface, and with no soft spots and low joints, this would cease to be the case, and the high speeds required to compete successfully with other forms of transportation could be maintained.

Following is an estimate of the annual saving resulting from the first three of the above items on a track having a freight traffic of 30 000 gross tons per day and 6 daily passenger trains.

Estimated annual saving, per mile of track

Assume average daily traffic as follows :

8 tonnage trains of 3 000 tons, 75 cars		24 000 gross tons	
4 less than tonnage trains of 1 500 tons, 40 cars		6 000 —	
Total freight per day		30 000 gross tons.	
6 passenger trains, 8 cars each			
Assume ruling grade of 0.5 %			
Maintenance of way :			
250 ties at $2.00			$500
Ballast renewal every 10 years, 2 000 cubic yards at $1.50 (material delivered)			300
Track labor			
Present cost (Acct. 220) for assumed traffic		$1 600	
Less cost with concrete base			
Labor on sidetracks, 0.5 mile per mile of main.	$200		
Renewing rail, 6 year life at $750.	125		
Track walking and inspection, 1 man at $1 200 per year covering 6 miles	200		
Miscellaneous labor	200		
Total		725	
Net saving track labor			875
Total saving, maintenance of way.			$1 675
Maintenance of equipment :			
Present cost per day			
18 locomotive miles at $0.40			$7.20
760 freight car miles at $0.16			12.16
48 passenger car miles at $0.032			1.54
Total per day			$20.90
		or $7 628 per year	
Assuming a reduction of 20 % annual saving would be			$15.26

Fuel :

Assuming a decrease in train resistance of 1 pound per ton, equivalent to a vertical lift of $\frac{5280}{2000}$ or 2.64 feet per mile.

Total gross tonnage per day :

Freight	30 000
Passenger	1 400
Locomotive.	3 600
Total	35 000

Total per year, 12 775 000 gross tons.
Coal saved per year, 12 775 × 2.64 × 5 lb. = 84 tons.
Saving per mile per year, 84 tons at $5.00 = $420

Increased tonnage rating :

Present train resistance	6 lb. per ton.	
Grade resistance, 0.5 % grade	10 lb.	—
Total	16 lb. per ton.	

Assuming a decrease in train resistance of 1 lb. per ton, the total resistance would be 15 lb. per ton, and the number of tonnage trains would be reduced by $\frac{1}{16}$, or 182 trains per year.

Cost per train mile, not including fuel :

Train and engine men	$0.40	
Engine house service	0.10	
Train and engine supplies	0 10	
Maintenance of locomotive	0.40	
Interest on locomotive	0.10	
Total	$1.10	
Saving per year, 182 trains at	$1 10	$200
Total saving per mile per year		$3 821

Equals 10 % of the estimated cost.

If ruling grades comprise 10 % of the division, the application of a permanent roadbed to the ruling grades only would result in a saving per mile due to increased tonnage rating of 10 × $200 or $2 000. Adding the other savings amounting to $3 621, the total saving per mile would be $5 621 or 14.8 % of the estimated cost. A similar estimate, based on a freight traffic of 40 000 gross tons per day shows a saving per year per mile of $4 950 or 13 % of the estimated cost; and when applied to ruling grades only, of $7 434 or 19.5 %.

The several parts of the present track are renewed at comparatively short intervals, and it is therefore proper to deduct from the annual saving as above estimated an amount sufficient to amortize the cost of the concrete base during its probable life. If this life is 50 years or more, this amount is negligible; and if the life is 35 years it is 1 % of the first cost, assuming interest at 6 %.

In the above estimate the reduction in maintenance of way expense is the only item for which there exists a reliable basis. The figure of $1 600 per mile per year used for the present cost of track labor may seem excessive to one accustomed only to figures representing average costs over an entire railway system or an entire operating division; but when the cost of track labor on the heavy traffic sections is kept separately, it will be found to be much higher than the average. The figure used is based on actual costs on the *Pere Marquette*, where a comparison of the cost of track labor on the different operating divisions in 1923 and 1924 indicates that such cost is approximately given by the formula :

$$\text{Cost of track labor per mile per year in dollars} = \$275 + \frac{\text{gross tons per year}}{8000}.$$

It is assumed that the cost of maintaining equipment would be reduced 20 %. This may be either too high or too low, as there is no basis for an estimate; but it

is reasonable to suppose that equipment running over a perfectly smooth track would require less repairs and would have a longer life than if subject to the innumerable shocks inherent in operation over the present type of track.

There is likewise no definite basis for the assumption of a reduction in train resistance of one pound per ton. There is doubtless a large amount of energy lost in shocks at rail joints in the present track structure; and, due to the imperfect elasticity of the roadbed, a further amount is lost in depressing the track and pushing the main track wave ahead of the locomotive and smaller ones ahead of each truck. This loss would be practically eliminated with a track of the type proposed, but the decrease in train resistance which would result can only be determined by experiment.

The conclusions to be drawn are that, for roads with heavy traffic, track of the permanent type would result in a reduction of maintenance of way expenses that would yield a moderate return on the investment cost; would probably further result in a large saving in maintenance of equipment and cost of transportation; and would permit the safe operation of trains at considerably higher speeds than are now permissible.

With a moderate return assured on the investment from the saving in maintenance of way expense alone, it would be well worth while for any road with heavy traffic to install one or more experimental sections of permanent track in order to determine its other economic values, and to develop by trial the details of a practical design.

[625 .143.5]

An examination into the causes of the failure of steel rails,

By Ernest A. DANCASTER, M. Sc., A. I. C.

Figs. 1 to 7, pp. 683 to 693.

(*The Railway Engineer.*)

The cause of the failure of steel rails in service has always been a question of great interest to railway engineers, but it is only during the present century that this question has been systematically investigated on scientific lines. A series of investigations into the microstucture of rails which have failed in service was commenced some years ago by the writer in conjunction with Mr. W. H. Shortt, M.Inst.C.E., and the method of examination then developed is still in use.

Full particulars of every fractured or flawed rail are sent to the laboratory, together with the defective pieces of the rail. The data cover, amongst other things, the make of rail, its length of service, the loss of weight during service, an estimate of the traffic it has been called upon to carry day by day, and the position of the fracture or flaw.

The examination of the piece of rail is carried out in the following manner. Two adjacent transverse sections, about 1/4 inch thick, are cut as near the fracture as possible, or through the flaw in the case of a longitudinal fissure. One of these sections is faced, the back and sides are coated with an acid-resisting medium, and the section is kept for two hours in a bath containing a 20 % solution of sulphuric acid at 60° C. It is

Fig. 1. — Microphotographs of areas containing abnormal structure in neighbourhood of flaws due to pipe. (× 25 diam.)

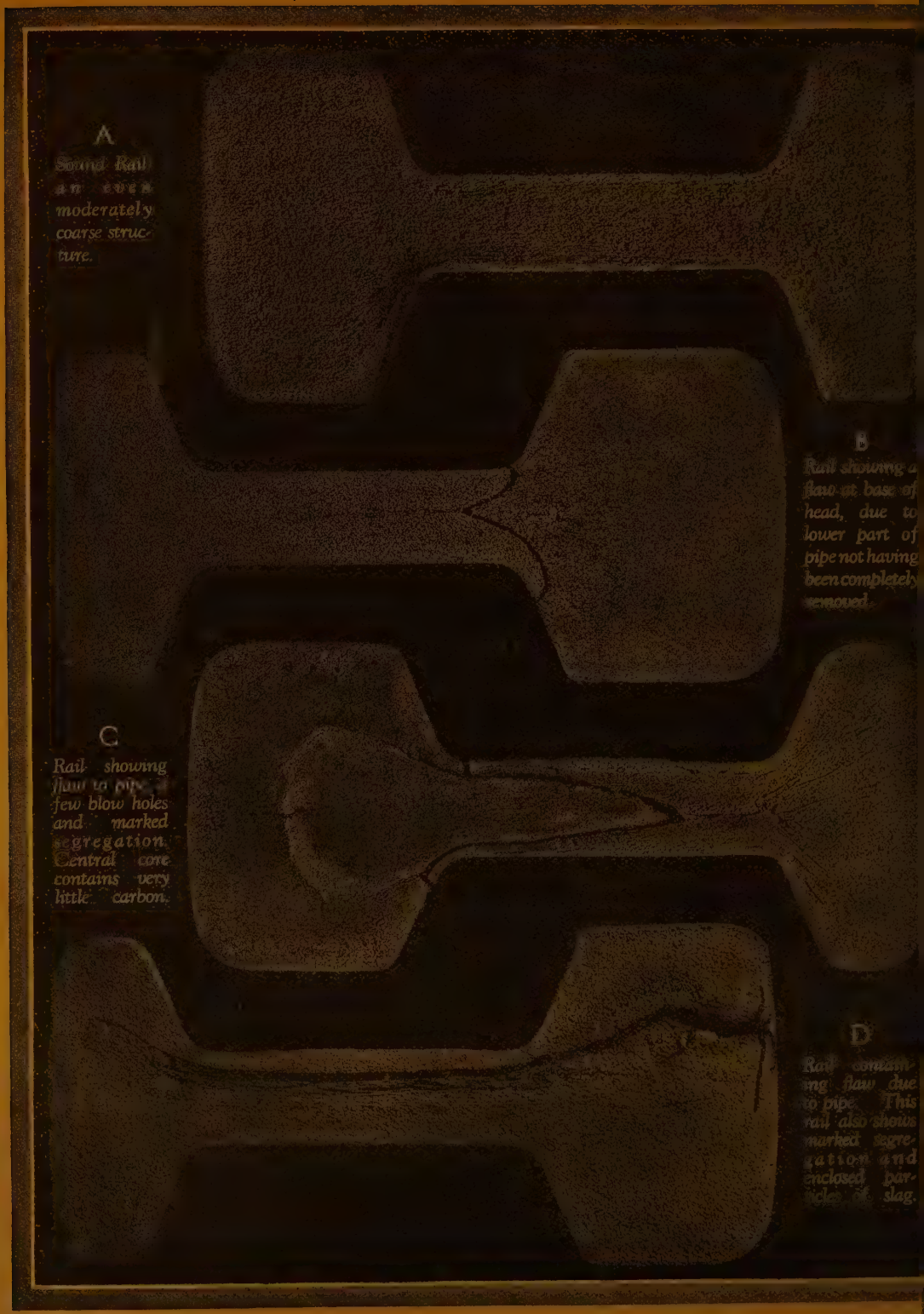


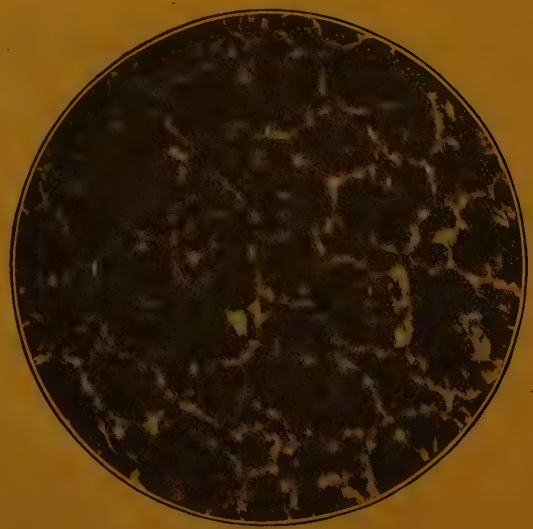
Fig. 2. — Transverse sections of rails etched with 20 % sulphuric acid.

E
Rail containing flaw due to pipe and showing marked segregation
F
Rail showing flaw due to pipe and also blowholes
G
Rail showing flaw due to pipe, accompanied by segregation and enclosed particles of slag
H
Rail showing flaw due to pipe, accompanied by segregation

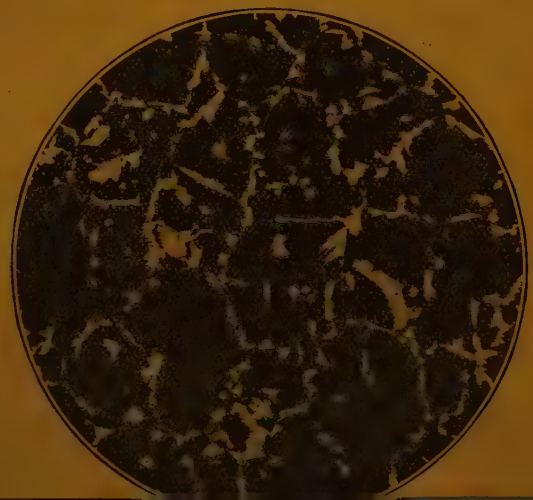
Fig 3. — Transverse sections of rails etched with 20 % sulphuric acid.

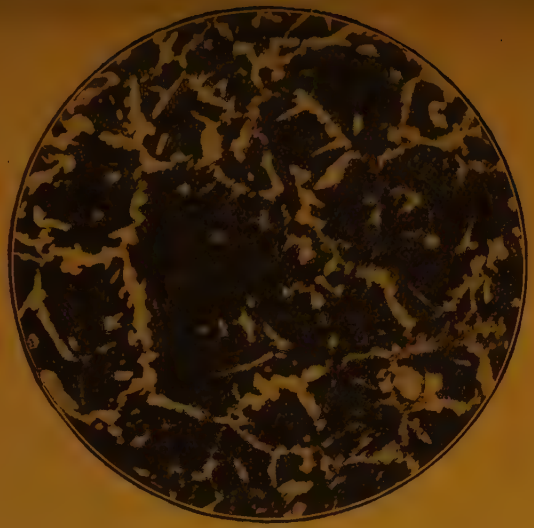
Fig. 4. — Types of microstructure found in rail steel (× 100 diam).

Type A. — Very fine network. Carbon 0.45 to 0.50 %.

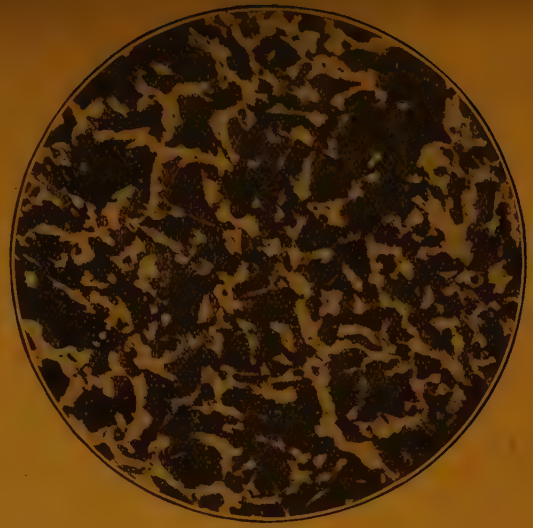


Type B. — Fine network. Carbon 0.43 to 0.45 %.

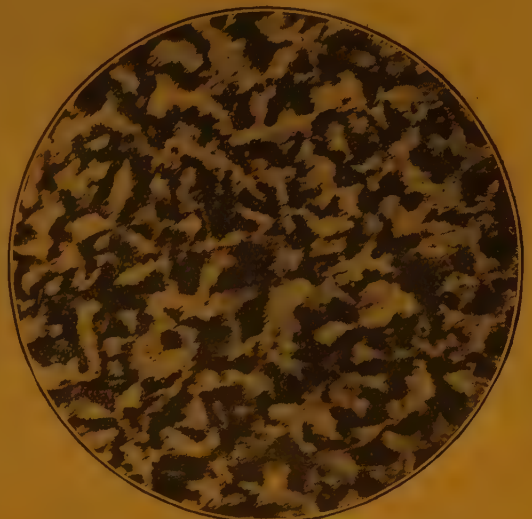




Type D. — Thick network. Carbon 0.40 to 0.42 %.



Type E. — Granular network. Carbon 0.38 to 0.41 %.



Type F. — Granular. Carbon 0.35 to 0.38 %.

Type G. — Low granular. Carbon 0.30 to 0.35 %.

then taken out of the bath, thoroughly washed, dried and examined, a natural-size photograph being taken of the etched surface. The examination of this coarsely etched section gives much information as to the nature of the metal, the presence of pipes, blowholes, etc., and any differences of structure which may exist in different areas of the section, thus serving to indicate which parts of the second section should be chosen for examination under the microscope. Eight etched rail sections are shown in figures 2 and 3; these illustrate various types of structure usually found.

Small pieces are cut from selected parts of the second section. A piece from the centre of the head and a second piece from near the running surface are always chosen. Sometimes this is all that is necessary, but more frequently it is also desirable to examine pieces from other parts of the section, either because of variability of structure or because of the presence of flaws. The selected pieces are polished and etched, care being taken that the surface etched is the one contiguous to the etched surface of the first section, so that the two etched surfaces exactly correspond. The polishing and etching are carried out in a room set apart for this purpose and kept as free from dust as possible. The blocks are first filed smooth, then the file marks are removed by rubbing on dry carborundum cloth, the polishing is continued by rubbing on successive pieces of carborundum cloth, each cloth being finer than the preceding one, and finally on exceedingly fine-grained carborundum papers which have been specially prepared for this work by the Carborundum Co., Ltd. They are then polished with « Diamantine » powder on a rapidly rotating block covered with a wet cloth, the « Diamantine » being placed between the cloth and the block, so that only the finest particles work through the cloth to the polishing surface, and the scratching effect is reduced to a minimum. The polished specimens, which should be smooth and even and free from scratches, are now examined under the microscope. This examination reveals any slag areas and minute fissures which may be present. The polished specimens are then etched in order to develop the microstructure. A great variety of etching media is available for this purpose, two of the most suitable for all ordinary purposes being a 1 % solution of nitric acid in alcohol and a 5 % solution of picric acid in alcohol. Occasionally it may be desirable to have recourse to a solution of iodine or to heat tinting, but the above-mentioned media will be found sufficient in by far the greater number of cases. Whichever medium is used, as soon as the etching is judged to have proceeded far enough, the block is washed thoroughly, first with water, then with methylated spirit, and finally dried in hot air, care being taken that the etched surface is not touched in any way. The etched blocks are again examined under the microscope and selected points are photographed, using a magnification of 100 diameters. In certain cases of abnormal structure it is necessary to employ a higher magnification than this, and it is frequently found desirable to use a magnification of only 25 diameters in order to show areas of abnormal structure. Two photographs of such areas are shown in figure 1.

The microscopic examination of the etched specimens under the usual magnification of 100 diameters does not enable us to identify the various constituents of the metal. It does, however, reveal the size and type of the grains of pearlite and the distribution of the grains of manganese sulphide, which are to be seen as small dove-coloured areas embedded in the ferrite. The identification of the constituents is not usually necessary in the examination of rails. When this is required, recourse must be had to a higher magnification (from 500 to 1 000 or more diameters). The chief constituents of rail steel are *ferrite* and *pearlite*. The former consists of iron almost

free from carbon, and the latter is a mixture of *ferrite* and *cementite* (a carbide of iron, Fe_3C). Pearlite occurs in two forms : in the most usual form (to which it owes its name) it consists of alternate lamellæ of *ferrite* and *cementite*; in the second form, it consists of irregular granules of the same two constituents. Occasionally, however, constituents of the *austenite* series are found, such as *martensite*, which is characteristic of quenched steels, *troostite* and *sorbite*. When these are present, or when their presence is suspected, the examination must be made, as already stated, under a higher magnification. A considerable amount of experience is required to distinguish between these constituents, which form a continuous series. The well-marked interlacing needle-like crystals of *martensite* are, however, easily recognised. This constituent is sometimes found in the forged ends of crossing rails, but is never a constituent of any ordinary rail.

Sometimes it is advisable to take « sulphur prints » in order to discover the distribution of the sulphur over the cross-section of the rail. A piece of gaslight paper moistened with a 3 % solution of sulphuric acid in water is laid on the dry polished surface of the rail section and carefully pressed down with the finger. It is left for one minute, then removed, washed, fixed with hypo, and again washed and dried in the usual manner of treating a photographic print. The sulphides present in the metal at the surface of the section react with the silver salts of the photographic paper and a record of their distribution over the section is obtained.

The chemical examination does not require a detailed description. The percentages of phosphorus, sulphur and silicon present are ascertained by means of any of the standard methods. The carbon and manganese are determined colori-metrically, the drillings required for the determination of these two constituents being carefully taken from as nearly as possible the actual points photographed at the centre of the head and near the running surface. By following this method, the percentage of carbon actually found agrees closely with that indicated by the type of microstructure. Unless the carbon is taken from very near the spot examined, this agreement will be much less evident.

The investigations have shown that rail failures may be divided into two broad classes : *a*) failures of sound rails, and *b*) failures of rails containing flaws. The failures of sound rails fall into two sub-divisions, according to the nature and position of the fracture; namely, failures where the fracture is close to the end of the rail, generally passing through one or more of the fishbolt holes, and fractures clean through the rail from top to bottom. The failures of flawed rails may also be sub-divided according to the nature of the flaw, thus :

1) Flaws due to pipes.
2) Flaws due to transverse cracks.
3) Flaws due to blowholes in excess.
4) Flaws due to excessive segregation.

With regard to the failure of sound rails, it has been found that the majority fall into the first sub-division and that the fracture generally passes through the first fishbolt hole. Fractures clean through the rail may occur in any position, but they are usually found near the end of the rail. Where the traffic is in one direction only, the fractures are almost always found near the leading end, *i. e.*, that end of the rail which meets the traffic first. Seeing that the bulk of the fractures occur in the neighbourhood of the joint, it is evident that the presence of the latter is the primary cause of this class of failure.

Chemical composition has, of course, a considerable effect upon the ability of the metal to stand the wear and tear of traffic, but in actual practice it is found that apart from the variation in the carbon percentage of the steel, the amounts of the added or accidental con-

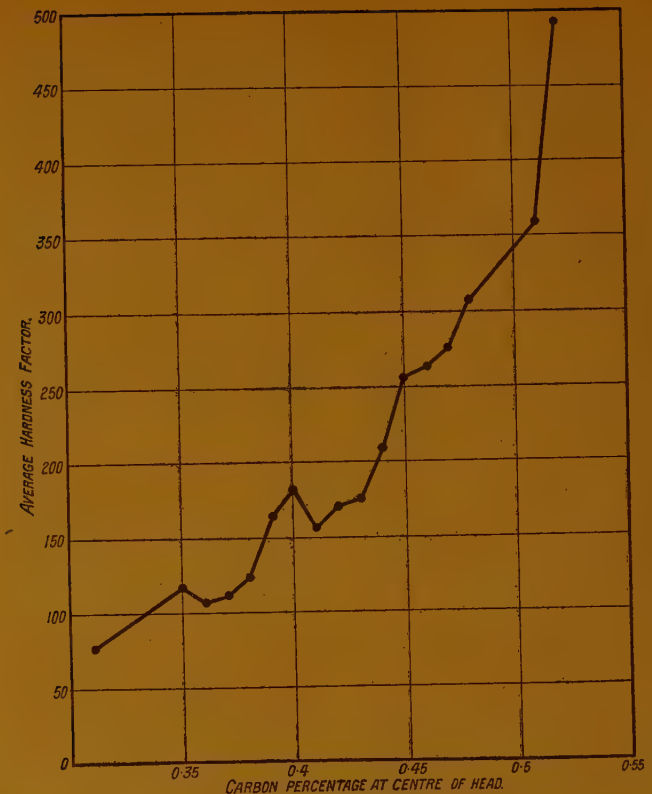


Fig. 5. — Relation between the hardness factor and the percentage of carbon.

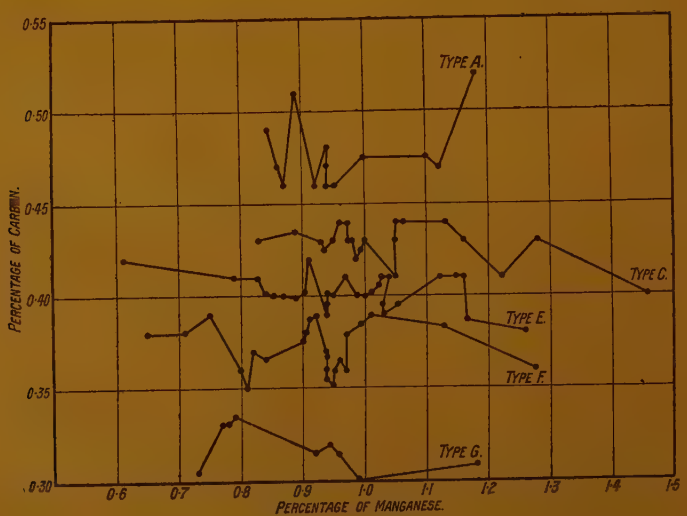


Fig. 6. — Relation between percentage of carbon and manganese and the microstructure.

stituents such as manganese, sulphur, phosphorus and silicon, have but little effect, because these are all kept well below the limits at which any harmful results would be produced. In the case of manganese, it is not sufficient to keep the amount below the maximum limit. This is an intentionally added constituent of the steel, and it is necessary that the amount present should be large enough to ensure the desired effect. The variations in the percentage of carbon are of great importance because of their bearing upon the wearing qualities of the rail.

The resistance of a rail to the wear and tear of traffic is obviously directly proportional to the length of time it is in the road, and also to the number of trains per day it has been called upon to carry, whilst it is inversely proportional to the loss of weight which it has suffered during service; in other words, calling the resistance of the rail to the wear and tear its *hardness factor* H, we have

$$H = \frac{S \times T}{L}$$

where S equals the service in years, T the traffic in trains per day and L the loss of weight in pounds per yard.

The value of H has been calculated for all rails examined, and the diagram in figure 5 shows the relation between the hardness factor and the carbon percentage of all the rails found fractured or flawed during five consecutive years. Each dot on the curve represents the average hardness factor of all the rails containing the percentage of carbon indicated, and the irregularities in the curve are mainly due to an insufficient number of rails having been examined to obtain the true average value of the hardness factor. Thus, the point at H = 76 and C = 0.31 % represents only one rail, and there is every reason to suppose this rail had a low hardness factor. The rail was a flawed one, and it is found that rails containing flaws usually have a lower hardness factor than do sound ones of the same carbon percentage. Judging from the general shape of the curve, the average value of H for a rail containing 0.31 % of carbon should be about 100. Notwithstanding the irregular nature of the curve, it is obvious that the wearing qualities of a rail are approximately proportional to the square of the carbon content, so that there is every inducement to make use of rails containing the highest possible percentage of carbon.

There is also a relationship between the carbon percentage and the type of microstructure. As already stated, the microstructure of ordinary rail steels is simply a combination of *pearlite and ferrite*. Leaving aside the question of size of granules and confining our attention to the ratio of the areas of *pearlite* to those of *ferrite*, it is found useful to divide the microstructure into seven types as shown in figure 4. Types A to D all show a definite network of *ferrite* enclosing the granules of *pearlite* and are described as « network structures »; types F and G show a considerable groundwork of *ferrite* interspersed with granules of *pearlite* and are described as « granular structures »; while type E is intermediate in character and is described as a « granular-network ». There is nearly always a close agreement between the carbon percentage and the type of microstructure, but occasionally a rail is found which does not show this conformity.

The amount of manganese usually present in rail steel has very little effect upon the type of microstructure. Apparently a large excess of this constituent slightly raises the type and a large deficit slightly lowers it, as shown by the diagram in figure 6. Thus, the rail shown at C = 0.40 % and Mn = 1.46 % has a microstructure of type C, although the carbon percentage corresponds to one of type E, whilst the rail shown at C = 0.42 % and Mn = 0.61 % has a

microstructure of type E although the carbon percentage corresponds to one of type C. Manganese has a tendency to increase the size of grains of *pearlite*, and also affects the structure owing to the formation of sulphides and silicates.

The microstructure has an important bearing upon the wearing qualities of the metal. Apart from the types of structure already dealt with, which depend mainly upon the amount of carbon present, the size of the constituent grains must be taken into consideration. A small-grained structure such as that shown at A in figure 7 is very desirable, whilst a large-grained one such as that shown at B is an indication of reduced ductility and should be avoided. This difference in the size of the structure has nothing to do with the carbon percentage; the carbon in A = 0.44 % and that in B = 0.45 %. It is mainly a question of mechanical and thermal treatment. Sometimes long bands of *ferrite* are present, thus producing lines of weakness along which fractures may develop, and occasionally a lattice structure, such as that shown at C, figure 7, is found. This type of structure is associated with brittle, defective metal, and is very undesirable. Sometimes two quite different structures are found existing side by side as shown at D. This is, of course, a very undesirable state of affairs, and is usually, if not always, associated with segregation. Manganese sulphide areas should be looked for. These are found embedded in the *ferrite*, and their presence, especially in a rail containing a comparatively high percentage of sulphur, is an indication that the manganese has done its work efficiently, having converted the deleterious iron sulphides into the comparatively harmless manganese compound.

Turning to the question of flawed rails, it should be noted that flaws due to the presence of pipes are the most numerous and important, although failures due to this cause are, at the present time, comparatively infrequent in this country owing to the careful inspection carried out at the various rolling mills, which ensures that practically all piped rails are discovered before they leave the works. A flawed rail may, of course, belong to more than one of the sub-divisions : thus, a rail containing a pipe may also have an excessive number of blowholes or show excessive segregation. Pipes are produced in the ingot. They are due to the contraction of the metal during cooling, and their presence in rails is owing to insufficient cropping of the ingot before rolling, though occasionally a pipe may extend so far down the ingot that no amount of cropping will remove it altogether.

Flaws consisting of transverse fissures may also occur, but they are comparatively rare. They may always be distinguished from a fracture by the unwelded surfaces. The flaw is, of course, continuous with the fractured surfaces of the sound part of the metal. Transverse fissures are, like pipes, due to contraction of the metal of the ingot during cooling. The molten metal may « seize on » at different levels, and, as the mould is expanding whilst the ingot is contracting, a transverse crack is likely to be produced. Similar cracks are also formed when the exterior of the ingot is cooled too rapidly, or when a cold ingot is heated too quickly so that the expansion of the exterior of the ingot is too rapid.

The presence of blowholes in excess in the steel prevents the thorough welding of the metal and produces soft spongelike areas which crush down under pressure. Actual fracture does not usually take place because the rails become so distorted that they must be removed from the track before this stage is attained. The same spongy effect may also be produced through the enclosure of particles of slag or other foreign matter. According to Mr. R. Job [1], all cases of flowing over at the sides of the head are

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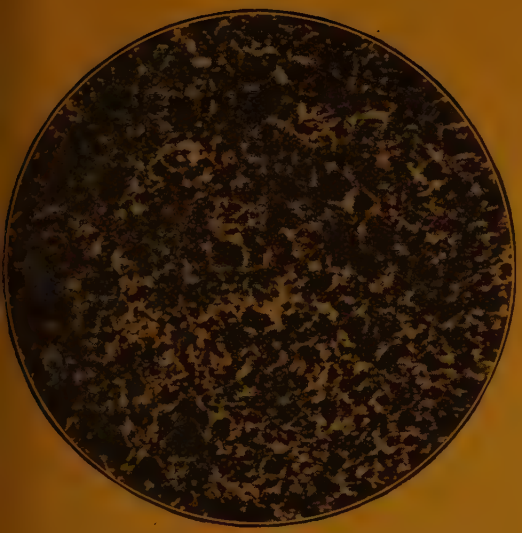
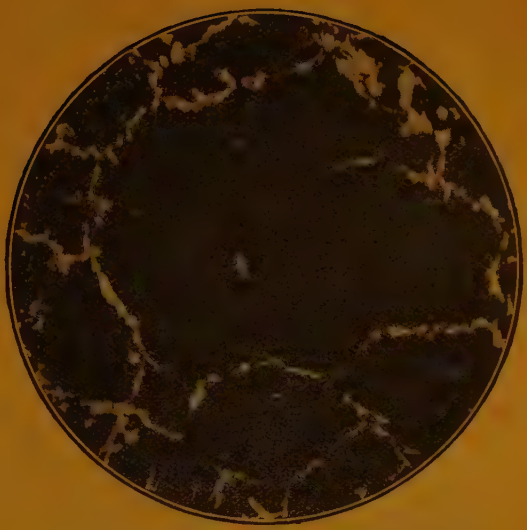
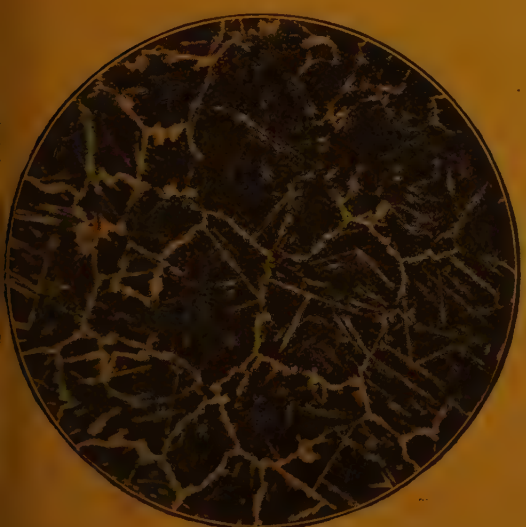
[1] R. Job, *The Iron and Steel Magazine*, 1905, vol. X, p. 97.



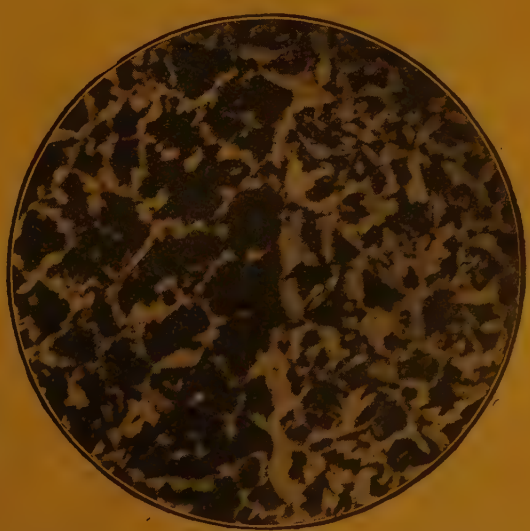
Type A. — Small-grained structure possessing good wearing qualities.



Type B. — Large-grained structure indicating reduced ductility.



Type C. — Lattice structure characteristic of brittle, defective metal.



Type D. — Two adjacent structures producing lines of weakness at their junction.

Fig. 7. — Good and bad types of microstructure.

due to the presence of blowholes or other unsoundness near the surface, and even rails containing as little as 0.33 % of carbon will not flow over under heavy traffic provided the steel is sound. Cases of flowing over are certainly found amongst such unsound rails, but many examples of this effect are also found in perfectly sound ones, especially when the carbon percentage is fairly low. Blowholes are produced in the ingot during solidification by the expulsion of the gases (mainly hydrogen, nitrogen and carbon monoxide) dissolved in the molten metal. When not excessive in quantity they are of no great importance, and even when they are in excess the harmful effect is considerably reduced if they are sufficiently deeply seated.

The failure of rails through segregation of the constituents is very unusual, but such cases do occasionally occur. A certain amount of segregation is always found because there is always some variation in the composition of the metal between the centre and the outside of the rail. This is due partly to the different fusibilities and different densities of the constituents, and partly to the strong affinity which some of the constituents have for each other, *e. g.*, manganese for sulphur. This segregation is very obvious when the distribution of the sulphur is studied by means of sulphur prints; it is, however, comparatively rare for the defect to attain such proportions as to become injurious. Frequently when excessive segregation is found in a rail it is accompanied by other defects. Indeed, this is only to be expected, because as solidification takes place the impurities are gradually expelled into the still molten portion of the metal, so that they are concentrated or segregated in the last portion to solidify, that is to say, around the pipe. Therefore, if the pipes are removed by efficient cropping, the remaining portions of the ingots will consist of metal which is equally free from pipes and from excessive segregation.

In conclusion, it may be said that the foregoing research has proved that the presence of the joint is mainly responsible for the failure of sound rails; that the wearing qualities of a rail are proportional to the square of the carbon contents between the limits 0.30 and 0.55 %; and that both the wearing qualities and the approximate carbon percentage can usually be determined from an examination of the microstructure. The metal should possess a small regular microstructure containing very little ferrite, and should be free from unsoundness of any description, whether pipes, cracks, blowholes or segregation.

The author desires to thank Mr. A. W. Szlumper, C. B. E., M. Inst. C. E., for permission to publish the above information, and Mr. W. H. Shortt for his helpful criticism and advice.

[625 .145.3 (.73) & 656 .281 (.73)]

Frisco wreck at Victoria, Miss., due to transverse fissure.

Fig. 1, p. 695.

(*Railway Age*, 5 December 1925.)

Early in the morning of 27 October, St. Louis-San Francisco train No. 108, the Sunnyland, was derailed on a 40 foot embankment a short distance south of Victoria, Miss., resulting in the killing of 23 people and the injury of more than

80 others. The derailment was caused by the breaking of a first quality open hearth rail of 90 lb. A. S. C. E. section rolled at the mill of the Tennessee Coal, Iron & Railroad Company at Birmingham, Ala., in October, 1918, and laid in track in April, 1919.

This rail was inspected by the Robert W. Hunt Company at the time of manufacture and the records of this company show that the chemical composition of the heat from which the rail was rolled conformed to standard specifications and that all of the rails from the heat, 180 in number, were accepted. The rail which failed, which was 33 feet long, was a « G » rail well removed from the top of the ingot. It broke 13 ft. 8 in. from one end. The failure was due to a transverse fissure which, as shown in the accompanying illustration, extended to within 1/32 inch of the surface on the gage side of the rail and to within 1/16 inch of the top. Being thus entirely surrounded by sound metal it was impossible of detection prior to failure.

As is also indicated by the photograph the rail was not worn appreciably. The track conditions were exceptionally good, so that the rail was not receiving undue punishment by reason of inadequate maintenance. The train involved in the derailment was traveling north and the accident occurred on a tangent 2 300 feet north of the end of the nearest curve on a 1 % descending grade. The roadbed at the point of accident was on an embankment about 19 feet wide and the track was laid with 20 ties per 33 foot panel with one foot of Birmingham slag ballast under them. A careful examination of the 2 300 feet of track approaching the point of derailment showed only 13 ties that could be classed

Fig. 1.

as defective in any way, or less than 1 % of the total number of ties, and no two of these occurred in the same panel of track. Even these ties were not decayed to the extent of warranting their removal from track and were considered good enough for more than a year of service. The track was fully tie-plated and spiked. The maximum variation of gage was found to be only 1/4 inch wide and 3/16 inch tight.

[625 .143.3]

BREAKING OF RAILS IN SERVICE DUE TO THE TRANSVERSE FISSURE.

Manchester and Victoria.

(*Railway Age*, 5 December 1925, p. 1018.)

On 25 August 1911, the transverse fissure was first brought into prominence as a defect in steel rails by the disastrous accident on the Lehigh Valley at Manchester, N. Y., which resulted in the death of 29 people and the injury of 62 others. On 27 October 1925, a defect of the same kind led to an equally disastrous accident on the St. Louis-San Francisco near Victoria, Miss., when 23 persons were killed and more than 75 persons were injured. The Manchester wreck disclosed the transverse fissure as a menace to travel for the first time and in the years that have intervened much study has been given to this form of defect. Yet 14 years after the original accident brought this type of rail failure to light, another accident occurred in which an even larger number of persons were killed and injured. Furthermore, the rail that caused the accident was rolled six years after attention was called to this defect by the Manchester accident. Even more distressing is the fact that there is still no agreement among rail authorities regarding the causes of this form of defect or regarding the measures that should be taken to eliminate it.

The transverse fissure is a particularly dangerous form of rail failure for it develops internally with no external evidence of its existence. As a result, it leads to failure without warning. Under such conditions, which make it impossible to detect it by an inspection of track, it is evident that the solution must be found in the discovery of the causes leading to the formation of this defect and then to the removal of these causes. Unfortunately the search for these causes has left much to be desired. There has been no united, concentrated study by those most concerned to get at the facts, regardless of whom they affect. Rather, there has been a disposition on the part of the manufacturers to endeavor to place the blame on the conditions of service, such as heavy wheel loads, deficient maintenance, etc., to which the rail is subjected, and an equal tendency on the part of railway officers to place the blame on conditions and methods of manufacture.

It is probably true that some reduction has been made in the number of transverse fissures as the result of the increased attention which has been given to rails in recent years. However, transverse fissures are still numerous and are therefore still a serious menace to railway travel. For this reason the railways and the rail manufacturers alike have a common interest and, in fact, a common duty and responsibility to throw aside prejudices and opinions and to engage in a joint scientific study to determine beyond question the causes of transverse fissures and the measures which must be taken to eliminate them. Until this is done the transverse fissure constitutes a challenge to the scientific ability of both. The repetition of accidents such as at Victoria 14 years ago after the problem was first brought to light, serves as an indictment of our metallurgical talent which calls for the inauguration of renewed scientific investigation of this problem that will be without prejudice and prompted solely by a determination to get at the real facts.

Transverse fissures due to high wheel loads.

(*Railway Age*, 26 December 1925, p. 1181.)

WASHINGTON, D. C.

To the Editor :

Your interesting and timely editorial in the issue of 5 December, concerning the Manchester accident of 25 August 1911, and the Victoria accident of 27 October last, each of which was due to a transverse fissure in the rails, is noted with deep concern. Those two accidents were the most appalling which have occurred due to the presence of transverse fissures, involving the loss of over fifty lives and injuries to nearly two hundred persons. In the interim of 14 years other accidents have occurred from the same cause, involving loss of life and personal injuries, while the total number of known transverse fissured rails has reached an enormous number, between ten and twenty thousand.

The report of the Interstate Commerce Commission on the Manchester accident first brought into prominence, as your editorial states, this type of fracture, describing it and allocating it as a definite type. The report of 25 August 1911, went farther and explained specifically its formation in the following language :

« The cold rolling of the running surface of the head of the rail by heavy wheel pressures has introduced internal strains at and for a short distance below the running surface. These internal strains are of compression. ... It follows that there must be an opposite strain of tension to balance them in some other portion of the rail. ... The tensile component ... next below the part affected by compression ... leads to an explanation of the presence of fissures in the head where they are being formed. The introduction of internal strains ... seems adequate to explain the occurrence and frequency of these interior fissures. »

The report further stated that transverse fissures should not be found in new rails, those which had not been exposed to track conditions, and none have been found in such rails. In those early days unsuccessful efforts were made in quest of transverse fissures in new rails on the part of those who were unprepared to accept the physical and metallurgical reasons which were ascribed as the cause of their formation.

The problem is one of physics, as rails will fracture when exposed to strains which are beyond their ability to endure, the same as other engineering members will. The trouble seems to have been in the failure to recognize the influence and effects of intense concentrated loads, which are peculiar to and always present where loads are carried on wheels. Girder strength of the rail is not the prime consideration. If it were, rails would fracture from the base instead of the interior of the head. The crux of the problem is in the intense impinging pressure at the area of contact between the tread of the wheel and the head of the rail. The intense local strains of compression in this affected volume of metal are sustained by that zone without rupture. This part of the rail does, however, transmit pressure to adjacent portions of the head where the strains are converted to those of tension, and in such zones we have the nuclei of transverse fissures. The predominance of transverse fissures on the gage side of the head is accounted for by the increased wheel effects on that side.

It is well known that the harder rails, according to chemical composition, are the more prone to display transverse fissures, and without material change in shape of the head or showing much loss of metal by abrasion. Medium grades of steel, employed in forgings and structural members, are not strong enough to sustain present wheel loads. Whence it

appears that present service conditions demand the use of rails made of steels which are sufficiently rigid to retain their shapes but which display transverse fissures without warning. When upward of fifteen thousand rails display transverse fissures and no determinate cause is discovered attaching to the quality of the steel it would seem that the original contention in the Manchester report of 1911, that « the danger zone of steel rails had been reached and possibly entered upon by current railroad practices », had a basis of justification. It is futile to look for a remedy against the rupture of steel exposed to overstraining loads. There is none. Fourteen years experience on the part of the railroads with 15 000 fractured rails should be recognized as offering sufficient evidence on this point. How many rails containing incipient transverse fissures, undiscovered and undiscoverable, are now in the track is a most disquieting uncertainty. That additional accidents will occur, under present service conditions, is just as certain as it was the day before the Victoria accident.

In the consideration of transverse fissured rails, the query at the outset presents itself, what is there at the nucleus ? The answer to which is nothing. There is no foreign inclusion of any kind, and not even a characteristic difference in composition or structure in the contiguous metal. The space between the walls of a transverse fissure is a void. No manufacturing condition is known to influence the formation of a transverse fissure.

Cooling strains are set up in rails after the processes of fabrication are completed, and by some are considered the necessary precursors of transverse fissures. Each of the fifty million, or more, rails in service was subjected to cooling strains in no respect differing from the 15 000 rails which have displayed transverse fissures. Cooling strains are introduced in all rolled, forged and cast shapes, steel rails having no monopoly in this feature.

It is customary to hear transverse fissures spoken of by the use, or misuse, of the word « defect ». The word implies the existence of some primitive, inherent, condition which by sufferance is allowed to exist, and for which there is a definite responsible cause. Before this word can properly be used there must be knowledge of what the defect consists. A defect must be known as a definite entity or where not so known, should be qualified as a supposed defect. The reiteration of this word eventually creates the impression that there really is a defect in the steel, when as a matter of fact the most diligent search has failed to reveal any. If a defect, perchance, is identified a long step will have been taken toward its possible rectification or if not admitting of elimination its irremediable character will become established. When a defect is mentioned it is incumbent upon the assertor to describe it, if called upon to do so. The inadvertent use of this word has doubtless been largely responsible for the current impression that some remedial feature in the manufacture of steel is the precursor of a transverse fissure, the knowledge and neglect of which places the responsibility upon the steel maker for the prevalence of this type of fracture. This trend of thought runs through practically every general discussion of the subject. The matter of ultimate resistance of the steel and relations of the service stresses to it does not come up for consideration, hence no definite conclusions are reached, nor can there be any.

The Bureau of Safety of the Interstate Commerce Commission has published reports of accidents due to transverse fissures from time to time since the report upon the Manchester accident. Other reports are now in progress, including the Victoria accident. Nine reports have been printed on this type of frac-

ture and copies thereof widely distributed. Different phases of the subject have been covered by these reports which are believed to have presented a comprehensive statement of the formation of this kind of fracture. In addition, the Bureau of Safety has prepared and published an extended description and compilation of the prevalence of transverse fissures on different railroads, showing the places where some eight thousand transverse fissured rails were located, according to mile posts. The activities of the Bureau on this matter have neither ceased nor have they been suspended. They are being continued along directions beneficial to all.

In your editorial the demand is made to « Throw aside prejudices, cease mutual efforts to place responsibility upon the other party; engage in a joint scientific study to determine beyond question the cause of transverse fissures and the measures which must be taken to eliminate them; ... the repetition of such accidents as Victoria serves as an indictment of our metallurgical talent. »

Nothing has taken place during the past 14 years to change or modify the views expressed in the first report issued by the Interstate Commerce Commission on this type of fracture, in which it was described, and the definite cause for its development given; namely, high wheel loads, which of course are aggravated by high speeds. Hope for improvement lies in the direction of finding a steel having a higher limit of endurance against present track strains, one which has a margin above any known grade of steel familiar to the arts. There is no hope for immunity against the display of transverse fissures in present track structures exposed to current strains.

A state of finality undoubtedly admits of being reached in the endurance of steels. If judgment is at fault in the belief that the prevention of transverse fissures under present wheel loads on present grades of steel is impossible, a great service will be performed by any person who will present conclusive evidence which will correct that judgment.

W. P. Borland,
Director, Bureau of Safety, Interstate Commerce Commission.

Are transverse fissures in rails due to high wheel loads ?

(*Railway Age*, 23 January 1926, p. 276.)

Numerous railway men have taken issue with the ideas expressed by W. P. Borland, director, Bureau of Safety, Interstate Commerce Commission, expressed in a letter published in the *Railway Age* of 26 December 1925, page 1181, commenting on an editorial on this subject in the issue of 5 December, in which he placed the responsibility for transverse fissures in rails on high wheel loads. The consensus of opinion among railway engineers who have also given this subject much study is that manufacturing conditions also contribute to this relatively new and dangerous type of failure. The basis for these conclusions is given in letters which we have received, some of which are published below. Prominent among these letters is one from George J. Ray, chief engineer of the Delaware, Lackawanna & Western, and formerly chairman of the Rail Committee of the American Railway Association. These letters follow :

Manufacturing conditions influence transverse fissures.

Hoboken, N. J.

To the Editor :

I have noted with interest your editorial in the issue of 5 December entitled « Manchester and Victoria » in which you plead for a united and concentrated

study of the cause of transverse fissures in steel rail. I have also noted with interest the letter from Mr. Borland, director of the Bureau of Safety of the Interstate Commerce Commission on the same subject, printed in your issue of 26 December.

What you have stated in regard to the disposition on the part of the manufacturers to place the blame for the development of transverse fissures on heavy wheel loads and deficient maintenance and equal tendency on the part of railway officers to place the blame on conditions and methods of manufacture would have more nearly represented the facts five or six years ago than today. It is my personal opinion that at the present time there is not much of a tendency on the part of the technical staff of the steel manufacturers to place all of the blame on the railroads nor do railroad officers, who are familiar with the problem, place all of the blame on the steel companies.

Furthermore, there has been for several years past a disposition on the part of the manufacturers and the officers of the railroads to try to determine the true cause of transverse fissures with possible methods for reducing the number or preventing them altogether.

For one I am quite willing to admit that wheel loads have much to do with the formation of transverse fissures, and after they are once formed, are entirely responsible for the development of these fissures. Certainly they would never develop without the wheel loads and the lighter the loads the longer it would take to develop the fissures.

Permit me to quote from my letter to the American Railway Engineering Association of 10 March 1921, at which time I was chairman of the Rail committee of that association :

« In the 1920 report of the Committee on Safety of Railroad Operation to the National Association of Railway and Utility Commissioners you will find the following statement concerning rails : « The published annual statistics on rail failures signify that the margin in strength is in many cases exhausted by the conditions which now prevail in the track. It is obvious that increased durability and safety in rails must be attained in one or both of two ways, either the physical properties of the steel must be raised or the working stresses lowered. » I am not an advocate of heavy wheel loads, but it is obvious that we cannot, consistent with economic or satisfactory operation, reduce the present average of the freight car axle load. The old light cars are gradually being replaced with heavier ones so that the average wheel load is constantly on the increase. Since the flow of metal, either on the surface of the rail or at some distance below the surface, is primarily caused by the heavier car wheel loads it is evident that the wear of the rail will be faster and the flow greater, unless some improvement is made in the physical properties of the steel. The working stresses in the rail can be lowered by the use of heavier rail, but increasing the rail section will not reduce the tendency of the metal to abrade or flow under wheel loads. A few years ago the manufacturers were strongly contending that excessive breakage and poor results with rail were due to the failure on the part of the roads to use a sufficiently heavy rail to take care of the heavy wheel loads and other requirements. The quite general use of much heavier rail has not eliminated the difficulties. In fact, the heavier rail has in many cases proven to be fully as troublesome from a breakage standpoint as the lighter rail. In connection with this, it is interesting to note that since some of the roads have started to use a heavier section than 110 lb. per yard, the manufacturers now claim that these heavy sections cannot be rolled under as rigid a specification as the lighter sections. They are not willing to guarantee as

good elongation for the heavy sections under the drop hammer.

« If all the rail rolled under the 1915 specifications had equally as good physical qualities as the best 50 % of the rail, there would be little cause for complaint and there would be little or no reason for a statement like that quoted above. »

In Mr. Borland's letter he makes the following statement :

« No manufacturing condition is known to influence the formation of a transverse fissure. »

I am willing to admit that we may not know positively of any specific manufacturing condition that influences the formation of transverse fissures, but we do know that transverse fissures are never developed in certain heats of steel and in some instances entire rollings are worn out in service without the development of transverse fissures. The assumption that the manufacturing conditions have nothing whatever to do with the formation of transverse fissures is not based on good judgment or full consideration of the data and facts which we have at hand. I have on many occasions furnished Mr. Howard, of Mr. Borland's department, with information to show definitely that certain heats of steel are subject to the development of transverse fissures while others rolled at the same time, laid in the same track and subject to the same wheel loads never develop transverse fissures. If the manufacturing conditions have nothing to do with the development of transverse fissures, what explanation have we for the above facts?

As an illustration, during the years 1911, 1912, 1913 and 1914 the Lackawanna railroad received 17 500 tons of 101 lb. rail from one mill, which we will designate as Mill « A » and 32 000 tons of the same weight of rail from another mill, which we will designate as Mill « B ». The rail was all laid in the main tracks and subjected to the same maintenance and traffic conditions. Some of the rail from Mill « A » is still in main line service. All of the rail from Mill « B » has been removed. The rail from Mill « A » developed 0.6 transverse fissure failures per thousand tons and gave very much better service from a wearing standpoint than the rail from Mill « B », in which 24.3 transverse fissures were developed per thousand tons of rail. Seventy-two heats had to be entirely removed from the track long before the rail was worn out, because of the excess number of transverse fissures developed in these particular heats. Most of the total transverse fissures in the rail from Mill « B » occurred in the 72 heats or in about one-eighth of the total number of heats. It certainly does not take a metallurgist or a physicist to convince a fair minded individual that the manufacturing conditions had something to do with the formation of transverse fissures in the rail from Mill « B ». At the present time we still have in service on one of our heavy branch lines 80 lb. Bessemer rail rolled in 1893. This rail is today carrying heavy loads and the average speed of trains is about as high as elsewhere on the railroad. Because of the worn condition of the head the area of contact between the head of the rail and the wheel is very much less than with our 105 lb. and 130 lb. rail on the main line. Certainly the internal strain is greater with this rail than it is with the heavier section where the area of contact is greater. Still we have never had a transverse fissure failure with this rail.

I have been keeping a careful record of all rail rolled for the Lackawanna during the past 17 years. I have also carefully tabulated the failures, including transverse fissures, the first of which developed on our road in 1909. I think I have read all of the pamphlets which have been issued by the director of the Bureau of Safety of the Interstate Commerce Commission on the subject of transverse fissures and while the infor-

mation submitted has been enlightening and worthy of careful consideration by all concerned, I am not convinced that I should throw away all of the evidence we possess and accept the theory that manufacturing conditions have nothing to do with the development of transverse fissures.

Admitting that the problem is one for the study of metallurgists and physicists, I agree that an earnest effort should be made on the part of all concerned to determine the cause of transverse fissures developing in certain heats of steel or certain rollings, whereas transverse fissures do not develop in other heats of the same rolling or in other rollings. If the physicists and metallurgists can help to solve this problem it will probably be possible to reduce very materially or possibly to eliminate the formation of transverse fissures.

G. J. RAY,
Chief Engineer, Delaware, Lackawanna & Western.

Cold rolling not the cause of transverse fissures.

FARGO, North Dakota.

To the Editor :

I have read with interest W. P. Borland's letter regarding the transverse fissure (*Railway Age*, 26 December 1925), wherein he definitely assigns the cause of such rail failures to the cold rolling of the running surface of the rail incident to heavy wheel pressures. In his opinion no feature of the manufacturing process enters into the cause of transverse fissures, and the steel maker is in no way responsible. Such an explanation is not convincing.

Although rails manufactured at the same mill and laid in contiguous track at the same time are all subjected to identically the same cold rolling process only an occasional rail develops a transverse fissure. It has also been definitely established that certain rail heats show a decided predisposition to failure from transverse fissure, such failures frequently occurring in sufficient numbers to necessitate condemning these entire heats and removing all of the rails from the track. Other rail heats are entirely free from this type of fracture. It is remarkable that such a dissimilarity in result is obtained if the cold rolling process is alone responsible for rail failures from transverse fissures.

Rails of the lighter weights 56, 66 or 72 lb., do not develop transverse fissures although such rails have in many cases been subjected to the cold rolling process for many years longer than the comparatively modern heavy rail. The transverse fissure is also peculiarly confined to rails manufactured by the open hearth process. I am familiar with a territory where many miles of open hearth rail are followed by a long stretch of Bessemer rail, all 90 lb., both types laid in the same year and both subjected to the same traffic and cold rolling process. The open hearth rail has developed a large number of transverse fissure failures while the Bessemer rail is entirely free from this particular kind of fracture. Why should this condition obtain if the cold rolling of the rail with its over-straining loads is the sole cause of transverse fissures ?

Among the rails that have failed on account of transverse fissures in the same stretch of track, some have only been in use a short time while others have undergone years of service before such failure finally occurred. Such a result would indicate an inherent difference in the quality of the rails. It would appear that some variation in the manufacture of open hearth rails of heavy section, perhaps very slight, causes a latent flaw or weakness in certain rails, and the cold rolling process to which the rails are subjected when in track develops this weakness to the point of failure.

C. H. BURGESS,
Road Master, Northern Pacific.

A wide field for investigation.

DALLAS, Tex.

To the Editor :

May I offer a contribution to the discussion of transverse fissures and their causes, with especial reference to Mr. Borland's letter in your issue of 26 December ? It seems to me unfortunate that the Bureau of Safety continues to insist that transverse fissures are due solely to the cold rolling effect of heavy wheel loads, and that there is no relief in sight with present grades of steel. It is entirely possible to bring about much improvement in this matter and I would like to point out some of the things that can be done.

As one concrete example, I will call your attention to a paper presented by P. H. Dudley at the June 1919, meeting of the American Society for Testing Materials. Dr. Dudley found that eight railroad companies reported 322 593 tons of rails rolled from reheated blooms with only 59 transverse fissure failures, and 559 644 tons rolled direct with 1 054 failures. The rails rolled direct developed 900 % more transverse fissures than the rails from reheated blooms. There was one mill which reheated the blooms, concerning which he had yet to hear of a single transverse fissure in its large output, and another mill which had only one against its output.

Internal stresses in the head of the rail due to cold rolling undoubtedly are an important factor in the formation of transverse fissures; but I think this is only one of several contributing causes, any one of which alone does not produce this type of failure. The principal causes are as follows :

1. Ingot defects, mostly segregation.

2. More or less faulty mill practice, causing incipient failures or high internal stresses in the head of the rail before it leaves the mill.

3. Imperfect counterbalancing of heavy freight locomotives. These engines, when operated at high speeds, produce stresses in the head of the rail in excess of the elastic limit of the steel.

4. The cold rolling effect of heavy wheel loads.

The cold rolling is a constant factor on any given piece of track. The other three causes are variable, which when present either singly or combined allow the transverse fissures to form. If this were not so, and the fissures were due to cold rolling alone, our track, after a certain length of time, would fail all at once and fly to pieces like the « one hoss shay ». It follows from this, that to cure the trouble we should work on the variable factors, ingot defects, mill practice, and the design and use of rolling stock. The only way to change the constant factor, cold rolling, is to go back to lighter equipment and smaller train loads, at an enormous loss of operating efficiency.

As to the first cause, ingot defects, improvement can be made by increasing the silicon in the metal, thus reducing segregation; by making ample discard from the top of the ingot; by rigid tests of the A and B rails, with possible rejection of all of the former. These things are understood by students of the matter, the difficulty is to bring them into use.

For the second cause, faulty mill practice, better rail is possible by reheating the blooms before they go to the rail mill; by increasing the number of passes through the rail mill; by finishing the rail at or just above the critical temperature where ferrite begins to separate from the solid solution; by reducing gagging stresses; by adopting, after investigation, some form of heat treatment. The sorbitic treatment seems to have possibilities.

Coming to the third cause, locomotive counterbalancing, the thing to do is rigidly to enforce maximum speed restrictions of heavy freight locomotives, espe-

cially the types with 10 coupled drivers, which are apt to have the main driver underbalanced. At speeds of 40 miles per hour and higher these engines can produce dangerous stresses in the head of the rail, especially on curves. The counterbalancing of heavy passenger engines deserves careful study, because of the speeds involved. One of the very great advantages of the three cylinder locomotive is that it offers relief in this direction. The same thing is true of electric-driven locomotives.

Girder strength may have considerable importance in the matter. I note that Mr. Borland says that if this were true « the rail would fracture from the base instead of the interior of the head ». As to this, I would call his attention to the second progress report of the Committee on Stresses in Railroad Track in the proceedings of the American Railway Engineering Association for 1920, pages 645-814, where the committee reports the finding of stresses of 52 000 lb. per square inch in the base of the rail and stresses 10 % higher in the head of the rail.

Certainly well informed people would not expect to find fully developed transverse fissures in unused rails, but the nucleus, the egg, as it were, from which the transverse fissure is ultimately hatched, has been and can be discovered before the rail is put into service. Dr. Dudley, in the paper above mentioned, described a method by which he had tested rails that had never been in the track, and which showed the sort of discontinuities that we would expect to develop into transverse fissures. This method could, if necessary, be used to test every rail before it was laid.

Moreover, the chemical composition of steel rail is still a fertile ground for research. The effect of varying proportions of carbon, of manganese, of silicon is by no means certain, especially in the presence of various impurities. How to get strength and hardness without loss of ductility; how to get ductility without the loss of the other qualities; these things are not settled. Neville and Cain, in the Bureau of Standards scientific paper No. 453, say, « Manganese had very little effect on the ductility of the alloys ». Rawdon and Sillers, in scientific paper No. 464, say, « The results obtained strongly support previous recommendations which have been made by different metallurgists concerning the advantages to be gained from the use of higher manganese, particularly in low and medium carbon steels », and « The addition of manganese causes a shift on the eutectoid ratio toward the left of the diagram ». If these things are true, and considering that greatest strength and finest structure, without loss of ductility, comes from working the steel just above the critical range, should we not increase our manganese and finish our rail at lower temperatures ?

The foregoing, I think, shows the field for improvement in this matter to be a wide one. Solving the problem means the getting together of all parties involved, the operating man, the civil engineer, the mechanical engineer and the motive power man, the designer and maker of locomotives, the metallurgical expert and the rail manufacturer. The thing is too complex to be mastered by approach from one angle alone.

R. G. WAGGENER,
Assistant Engineer, Texas & Pacific.

[621.13 & 621.335]

DIESEL AND STEAM LOCOMOTIVES, [1]

By Samuel M. VAUCLAIN,
PRESIDENT, BALDWIN LOCOMOTIVE WORKS.

(*Railway Review.*)

The steam locomotive has dominated transportation about one hundred years. It has been improved steadily. Its performance, through increased tractive power, has met the needs of modern transportation arising from the remarkable development of the world in the past fifty years. As a single, self contained power unit, it is without equal so far as its general efficiency and low cost of production are concerned.

When discussing railway motive power, the standard of comparison must be the steam locomotive, which occupies a strongly entrenched position both from practical and sentimental viewpoints. Its simplicity, ease of control and action under widely varying conditions of load, are factors that its rivals must embody if they are to compete successfully with it in every day service.

With the efficiency of modern internal combustion engines before him, the designer of railway motive power naturally is attracted by their possibilities. Thermal efficiency of these engines runs as high as 33 %, while the best steam locomotive gives about one-fourth of this performance. Even with this handicap, the steam locomotive is a remarkably flexible and reliable traveling power plant. To compete properly, no matter what the fuel economies may be, the internal combustion locomotive must approximate this flexibility and reliability. It must have ease of control, ability to start a full tonnage train, and be able to adapt itself rapidly to change in the physical conditions met in operation, such as variable speeds, gradients, curves and weather conditions. It must not be too complicated in detail, nor too heavy for the horsepower developed. Here then are the basic features the designer must bear in mind constantly. While a gain in thermal efficiency will warrant an increase in first cost, the price must not be so high as to offset the reduced operating costs.

European experience in Diesel locomotive construction has been more extensive than that of the United States, and some late opinions on comparative costs are interesting. J. W. Hobson, of R. & W. Hawthorne, Leslie & Co., says, in England, the cost of Diesel locomotives with hydraulic transmission has averaged about 1.48 times the cost of a steam locomotive of equal capacity, complete with tender; that the same measure of comparison for a Diesel-electric locomotive yields a ratio of 1.9. Dr. Herbert Brown of the Swiss Locomotive & Machine Works, Winterthur, Switzerland, says continental figures, on the same basis, yield an average cost for the Diesel-electric locomotive equal to 1.783 times the cost of the steam unit.

The problem divides itself naturally to cover two general classes of power: self propelled vehicles for light traffic, and locomotive units for hauling trains equal in tonnage to those hauled by steam locomotives.

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[1] Abstract of a paper read before the Midwest Power Conference (Western Society of Engineers).

In applying Diesel heavy oil engines to true locomotive units, the first consideration must be weight per horsepower developed. The heavier classes of Diesel engines in stationary service weigh from 170 lb. to 350 lb. per horsepower. In locomotive service the weight of the engine must be added to the weight of transmission, running gear and vehicle body. If a 1 000 H. P. Diesel engine of 170 lb. a horsepower is used in a locomotive its weight of 170 000 lb. would exceed the total weight of a complete steam locomotive of like capacity. During the World War some Diesel engines, showing a horsepower for every 65 lb. of engine weight, were built for submarine service. The locomotive designer needs this type of machine. The 1 000 H. P. rated Diesel-electric locomotive, built in Germany for the Russian railways (1924) has a total weight of 275 000 lb., or 275 lb. per horsepower.

The 1 000 H. P. rated Diesel-electric locomotive built in 1925 by the Baldwin Locomotive Works also weighs 275 lb. per horsepower. This indicates a close coincidence of best European and American practice and sets, for the present, this weight per horsepower as the standard for modern Diesel-electric locomotives. A slight decrease in weight is possible with an advance in locomotive horsepower; the present expectation in this respect is about 220 lb., which represents a ratio of about 1 : 1.5 when compared with an average steam locomotive. With a thermal efficiency of 3 : 1 in favor of the Diesel engine it appears that the added weight per horsepower is not a severe handicap. Ratios of this character, provided they go hand in hand with simplicity, should show attractive operating economies. What then should be the features tending toward simplicity of maintenance?

In discussing this phase of design it is advisable to review the history of internal combustion locomotives. It will be found the means of coupling, or transference of power from the prime mover to the driving wheels, is of greatest importance. The first real Diesel locomotive was that designed in 1909 by Adolph Klose, of Berlin, and constructed jointly by Sulzer Bros. of Winterthur, Switzerland, and Borsig of Berlin-Tegel, Germany. To show the boldness of the design, which was for 1 000 H. P., it should be compared with what is believed to be the first internal combustion locomotive ever constructed, the Daimler engine of 1891. As Dr. Diesel's oil engine had not been invented, this prime mover was one of the earliest types of internal combustion motor and developed only four horsepower.

The first Diesel locomotive.

Dr. Diesel's experiments with compression ignition began in 1893; but it was not until 1897 that the engine was considered of commercial value. The development had taken four years, and cost about $107 000. One of the earliest concerns to manufacture this type of prime mover was the firm of Sulzer Bros. of Winterthur, Switzerland. If followed naturally the first attempt at designing a full powered locomotive unit driven by a Diesel motor should be attempted by them. Associated with Sulzer Bros. were Dr. Diesel and Adolph Klose, who previously had cooperated with Diesel. In an effort to approximate the simplicity of the steam locomotive they coupled their engine directly to the driving gear by means of a jack shaft.

The steam engine, having its source of power generated outside the cylinder, will start directly under any load within its capacity, and can be controlled entirely by a steam inlet valve (throttle). The internal combustion engine, which generates its own sources of power directly within its cylinders, must have auxiliary starting means, and is operated preferably without load until proper thermal conditions are established. Here,

then, lay the problem of the first design: How to get a running start, and still maintain direct driving, with a speed beginning at zero under load.

Direct drive a failure.

Much of the history of this locomotive is obscure, as it was constructed at a period unfortunate for proper experiment and record. Beginning the design about 1909 it was not completed and ready for trial until 1913. It was intended for use on the Hesse-Prussian State Railways in Germany. As it fell upon war times, in 1914, its ultimate disposal is not now known generally. The direct drive proved a failure, but the experiment warned future designers against similar error. It proved positively that the Diesel motor could not be used advantageously for a direct drive in locomotive construction.

This pioneer Diesel locomotive is reputed to have weighed 95 metric tons (207 000 lb.), and as its rating was 1 000 H. P., the weight per horsepower was 207 lb. It was the 4-4-4 type, with two pairs of drivers and four-wheeled trucks, both leading and trailing. Its main motor was the two cycle, single acting type, with cylinders 15 inches in diameter, by 21 1/2 inches stroke, suspended in V form, longitudinally with the locomotive, and driving a transverse jack shaft with cranks located at 180°.

As it was not self starting, it was equipped with an auxiliary Diesel motor which could develop about one-fourth the power of the main motor. This auxiliary motor compressed air to a pressure between 600 and 1 000 lb. to the square inch. The air was stored in a battery of reservoirs and used for starting both motors. The locomotive was driven by air pressure in the cylinders until a speed of 6 1/2 miles an hour was attained. This speed was calculated as sufficient to produce compression and ignition of the oil fuel, which was then injected into the cylinders. In regular operation, the supply of compressed air was kept up by a multistage air pump, operated by pistons, placed in the V-space between the motor cylinders, and coupled to the main driving mechanism by means of links and rockers. The exhaust muffler and coolers for jacket water were placed longitudinally in the cab roof. The cab enclosed the entire machine.

Road tests were made on the Swiss Federal Lines between Winterthur and Romanshorn, and a speed of 62.5 miles an hour was attained. The air starting system gave considerable trouble, as the auxiliary engine was unable to supply the needed air. Irregularity of firing at low speed is reported also. This contributed, doubtless, to the breaking of the jack shaft which failed in 1913. The road tests were transferred to the Berlin-Mansfeld line of the Prussian State Railways early in 1914, and further record was lost in the hurly burly of war.

Internal combustion engines must be operated at speeds within their range of efficiency; and not from a zero start, as in direct connection. The designer, therefore, must find proper means for connecting the running prime mover to the locomotive driving mechanism. This transfer of power can be accomplished in three ways : 1) By mechanical (stepped gearing) transmissions; 2) hydraulic (flued pressure) transmission; and, 3) transmission of power by electricity.

Mechanical transmissions.

These are the ordinary change-speed stepped gearing, as applied in automobile practice. In locomotive construction they should be arranged preferably to give the same range of speeds forward and backward. Reversing is accomplished usually by bevel gearing. Mechanical transmissions require some sort of a friction clutch, and this feature gives trouble on the upper range of power. Probably 150 H. P. is the practical limit for mechanical transmission.

Hydraulic transmission.

This form of transmission employs oil as a power transference medium usually. It is attractive because of the possibility of infinite speed variations; some designs, however, fail to secure this possibility. Hydraulic transmission is suitable for locomotives of comparatively high power and is of lower first cost than electric transmissions of equal capacity. It has the disadvantage of concentrating its final driving power into one gear wheel, making it dependent on tooth contact and pressure. Its limitation is about 500 H. P.. although its advocates say it is adaptable to twice this figure. All designs employ a primary unit, or pump, which supplies oil under pressure to a secondary unit, or rotor. If the stroke of the pistons in the primary unit permits variation from zero to maximum, it follows that variability of speed can be obtained in the secondary unit, which is practically of reverse operation to the primary unit. The Hele-Shaw and Lentz transmissions are the best known examples of hydraulic transmission.

Lentz system.

The Lentz system, usually considered the most successful, does not give infinitely variable speeds. Because of simpler construction and the lower oil pressures, it avoids the operating mishaps of more complicated systems. It gives a definite number of primary speeds; intermediate speeds are obtained by bypassing the transmission oil, or by varying the speed of the main motor. As the oil pressures in the Lentz gear do not exceed 500 lb. a square inch at starting, and average 50 to 150 lb. when operating at speed, leakage is not so serious as with the other types of hydraulic transmission. Many European locomotives have been fitted with the Lentz gear.

The Schneider system is really a combination of mechanical and hydraulic transmission. The increased torque required at low speeds is obtained from the relative motion between the rotor and its casing. The energy due to slippage augments the power by an additional torque on the secondary unit. By this arrangement the usual power losses in hydraulic transfer are decreased and the general efficiency of the transmission is improved, especially at the higher operating speeds. The Schneider system is being exploited by the Swiss Locomotive & Machine Works, of Winterthur, which has constructed also a special 500 H. P. Diesel engine, which, with the transmission, is assembled into a complete locomotive unit. No reports of its trials are available.

Electric transmission.

In this system the prime mover is connected to an electric generator which supplies current to operate suitably disposed driving motors. Electric transmission gives a continually variable gear, allowing the locomotive to adapt itself advantageously to the speed of the prime mover. It makes driving easy and can be adapted easily to double end control. The installation is expensive, but from the railway operating viewpoint it is the most attractive transmission. Within recent years a number of Diesel-electric locomotives have been built in Europe and the United States.

The Lomonossoff locomotive.

That which has attracted most attention in Europe is the design by Professor Lomonossoff constructed at Dusseldorf, Germany, for the Russian Government Railways. It has a 2-10-2 wheel arrangement with five motor driven axles. It is arranged for double end control, with the drivers' cabins over the carrying trucks. The engine is a Diesel submarine type, four-cycle, six-cylinder unit, with compressed air fuel injector. Its normal speed is 450 revolutions a minute; and with a maximum capacity

of 1 200 H. P. The locomotive unit itself is rated at 1 000 H. P., and to verify this rating the machine was tested thoroughly on a special plant, similar to that of the Pennsylvania Railroad at Altoona. These trials form the subject of an elaborate discussion by Professor Lomonossoff, which has been translated into German, and published under the title of « Die Diesel-Elektrische-Lokomotive ». All electrical machinery is from the Swiss firm of Brown, Boveri & Co., briefly described as follows :

The generator has a capacity of 800 kw., at 600 to 1 100 volts, and is coupled directly to the prime mover by a flexible coupling. The exciter, carried on the end of the generator shaft, is excited by an auxiliary dynamo, operated from a storage battery. A peculiarity of the locomotive is its cooling system. The water flows through a piping system cooled by a fan. This is reported to be sufficient during « winter and ordinary temperatures ». Summer operation in such temperatures as are common in Russian Turkestan (120° Fahr.) will so overload the cooling system that a « cooling tender » must be used. This carries extra radiating equipment with fans driven by an auxiliary Diesel engine. If the weight of the extra cooler is considered, its thirty metric tons would make the engine figure 340 lb. per horsepower. This feature certainly is not in line with the « all around utility » ideas common with railway men in the United States.

The Lomonossoff locomotive was assembled at the Hohenzollern Locomotive Works, Dusseldorf, where tests were made on the roller plant. A comparison of these tests with those of a Russian type 0-10-0 oil fired steam locomotive was made. Dr. Herbert Brown of Winterthur, reports an average overall thermal efficiency of 7.43 % for the steam locomotive and 26.4 % for the Diesel-electric. This shows the Diesel locomotive to have been over 3 1/2 times as efficient as the steam locomotive. These are significant figures when first cost and maintenance charges are to be considered. Dr, Brown estimates the prime mover, including its auxiliaries, takes about 44 % of the total weight; the electrical equipment 30.5 %; leaving for the mechanical structure and running gear only 25.5 %.

Recent internal combustion locomotive construction in the United States has been along the lines of electric transmission only.

The Baldwin Locomotive Works produced a Diesel-electric locomotive of 1 000 H. P. in 1925. The prime mover is a two cycle, solid injection engine, of peculiar construction and very light weight. This machine represents the largest unit yet attempted in the United States. It is the result of extensive research and experimentation to fulfill the requirements of a reliable self contained unit, of simplest possible ensemble and ease of control. It weighs 275 000 lb. (275 lb. per horsepower) and is mounted on two six wheeled trucks. Traction motors are applied to four of the six axles. Its electrical equipment is of Westinghouse manufacture, with electropneumatic and magnetic controlling mechanism arranged for double end operation. The Diesel engine is the inverted V type with twin crank shafts geared to a central shaft on which is mounted the electrical generator. It is undergoing intensive tests at the yards of its builders and on adjacent railway lines at present.

Considerable time must elapse, and many millions of dollars be expended, in the development of the oil-electric locomotive before it will affect transportation service to any great extent. It has many apparent advantages that are not only of great interest to railway men, but very seductive to those who do not understand clearly all that is involved. At present construction costs are as two to one compared to steam power.

The internal combustion locomotive unit, whether constructed with direct drive, hydraulic or electric transmission, is yet in its infancy. The best engineering talent of the world is bending its energy to a successful solution of the problem. We will not know what difficulties in operation and safety will be encountered, until an appreciable number are in actual operation. The introduction of electric power for transportation purposes has been slow. The expense of installation, and the inconvenience and obstruction incident to its application, in switching yards and large railway terminals have militated against it. It has progressed step by step and is a necessity for all underground transportation, and for increasing the volume of traffic over sections of railway on which the steam locomotive has reached its limit.

If it be possible to produce a satisfactory machine at a price satisfactory to the purchaser, its greatest effect upon the transportation methods of the country will be to further the electrification of railways in general. This experiment is being tried in Switzerland now. If by the use of internal combustion locomotives all branch line and distributing service at railway terminals can be accomplished satisfactorily, and only main line service by overhead wires or third rails be required, we can then expect a more rapid development in the electrification of railways. It will be many years before the steam locomotive, owing to its simplicity, its serviceability and its low production cost will be relegated to the era of the past.

[656 .253 (.42)]

Signalling from a driver's point of view, [1]

by W. J. THORROWGOOD,

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The signals first used were to tell the driver when to start; these signals are now known as Starters. Very soon Home and Distant Signals were added, and, in principle, the system was very much as it is to-day.

The ideal of signalling to-day is to indicate to the driver the state of the road ahead to enable him to keep his train moving at the maximum speed under the conditions obtaining.

In theory, the present system of signalling, as far as the driver is concerned, is simple. In practice, it is so in the country districts where the traffic is not dense; but at a busy station, junctions and London terminal stations, signalling to the driver becomes complicated, owing to the number of aspects at one signal post he meets with at these places. At a country station he first sees the Distant signal, then the Home, Starter, and Advance Starter, one semaphore arm or light at each post, which he cannot very well misunderstand.

The general practice in signalling is to have a double aspect for each indication. Semaphore arm by day and red and green light at night, so that at a signal post with a single signal a driver has two aspects to consider or remember; but take the case of a driver on the Up Main line coming to the Bricklayers' Arms Junction signal post; he has to differentiate between thirty-four different aspects, taking into account the

(1) Paper read before the Institution of Locomotive Engineers, in London.

day and night indications; seventeen with semaphore arms plus seventeen with coloured lights. He has to stand at or run up to that signal and see one of the thirty-four different aspects exhibited by it, and know the meaning of the aspect as regards the route he is going over. Many similar cases could be quoted.

There are thirty-eight different forms or shapes of signals in use in this country to-day for Stop, Start, Pass, Shunt, Calling on, etc. The same form or shape of some of the signals has different meanings on different Companies' Systems. This is certainly not desirable.

Where signs are used, the diamond-shaped label on certain signal posts in connection with Rule 55 — the letter A for automatic signal posts, for instance — should be used and have the same meaning on all railways in the Kingdom.

The question arises whether the number of aspects and forms could not be reduced and the system of signalling considerably simplified, not only for the driver but to make the system of signalling more efficient in keeping trains running at the maximum speed and so add to the capacity efficiency of the railway lines, and whether one uniform system cannot be established throughout the country. I think it is not only possible but uniformity of Signal Aspects should be made compulsory.

The question of signalling is complicated by the fact that several types of trains have to run over the same lines :

1) Express passenger trains travelling at high speed;

2) Low speed passenger trains;

3) Heavy goods trains travelling at high and low speed;

4) The gradients met with;

5) The distance between stations or block posts;

6) On lines where electric traction has been installed, in addition to steam traction, the question is further complicated owing to the acceleration and deceleration of the electric trains being much higher than that of the steam trains.

Under these conditions the system of the two-position semaphore arm signal by day and two coloured lights by night for each signal is not sufficient or suitable to give the information necessary for drivers to maintain the maximum possible speed and to allow of the trains following each other as closely as possible and still maintain safety conditions, unless the number of Block Posts or Signal Boxes is increased and the length of the Block Sections arranged to suit the traffic. But the cost of establishing these Block Posts or Boxes and the cost of manual labour necessary for maintenance is prohibitive.

In the country districts where the traffic is dense and only steam traction employed, the difficulty may not be so great, but where fast trains are passing and the sections short, a driver has to reduce his speed, as the indication given him does not generally inform him of the position or condition of the signal ahead.

The first signal a driver comes to on approaching a Block post or station is the Distant signal and that tells him either : 1) all the signals at that post are « off » or in the Clear position or 2) that one or more or all the signals of that block post, Home Starter, Advance signals and Outer intermediate signals, where there are any, are in the « on » or Danger position and that he must reduce speed or be prepared to stop at any one or all of these signals.

The Distant signal is placed so far away from the Home signal that the driver can bring his train under control and stop at the Home signal if necessary. This distance must be arranged for the fastest and heaviest trains and, therefore, is longer than is necessary for the majority of trains, and time is lost in many

cases owing to drivers slowing down unnecessarily.

In dense traffic areas a distant signal is often placed under the Home signal. This combination makes the system a three aspect system as : 1) if both the Home and the Distant signal are in the « off », or Clear position, the driver knows that the Stop signal at the next post is in the « off » position; 2) if the Home signal is « off » and the Distant arm « on », the driver can pass the signal but knows that he may find the next Stop signal « on »; 3) If both the Home (or Stop) and Distant are in the « on » position, it is an indication that he must not pass that aspect.

But near terminal stations where the sections are short, this system of three-aspect signalling is still insufficient to allow of trains running at maximum speed.

The three-aspect colour light signal system gives all the indications given by the semaphore arms by day and lights by night, with the use of only three coloured aspects, Green, Yellow, Red, only one aspect at a time.

The three-aspect system answers well where there is only one type of traction but with mixed traffic, where it is dense, further facilities are required to maintain the maximum speed and a fourth aspect is wanted; if a fifth aspect is ever required, the fourth aspect can be repeated in the signals in the rear.

In practice, it is often found necessary where three-aspect signals are used to put up speed restriction indicators, showing the speed the driver has to run over the section immediately ahead. This, to all intents and purposes, is a fourth aspect and a single and double Yellow is a very good substitute for this.

Further, under the present system of signalling, a driver has in many cases to pass a Red light, or a semaphore arm of a Distant signal (with a fish tail) in the Danger position. In the case of a Home and Distant signal being on the same post, the driver has often to pass a Green and Red light. In some cases there may be as many as four semaphore arms on one post, in which case the driver has to pass three red lights or three arms in the « on » position. Therefore, under this system, no absolute Stop aspect alone can be given with the present semaphore signal, which is a very great disadvantage. The three-colour light signal system overcomes this difficulty, as Red is used as an absolute Stop signal in all cases where it is exhibited, but in dense traffic areas another aspect is wanted to give a preliminary warning to high speed trains and this is arranged for under the four-aspect colour light signal system, which has recently been proposed, and I may say is being installed between Charing Cross, Cannon Street, Holborn and London Bridge stations, which overcomes the difficulties I have mentioned above.

The colours decided upon are Green for Clear, Double Yellow for Warning, Single Yellow for Caution and Red for Stop.

It will be seen that there are three colours only, Green being for Clear, Yellow for Caution and Red for Stop. The shades of colours for these signal aspects need to be carefully selected and must be the same for all similar aspects.

A driver coming to and passing a green-coloured light signal is told that the line is Clear to the next signal and that he may find that signal, Green, *i. e.*, in the Clear condition or it will be a Double Yellow aspect.

If, when approaching a signal, the Double Yellow aspect is exhibited, the high speed driver will be given the « Warning » signal that the next signal ahead is Single Yellow and that he has full braking distance before he reaches the Stop signal. The Single Yellow aspect cautions the driver that the next signal ahead is Red or Stop condition,

and as he has reduced speed since passing the Double Yellow he must now, as he passes the Single Yellow aspect, be prepared to stop at the next signal.

In every case where a Red is exhibited it means Stop, Green means Clear and Yellow means either : 1) Warning or 2) Caution; — be prepared at the next signal which at present is in the Stop condition. The driver can only be told the position or condition of the signal ahead at the moment, as the signals are, as it were, in a state of flux dependent upon the condition of the road ahead.

The benefit of these Light Signals to a driver is that, as they take up less room than Semaphore signals, they can be placed very near to his line of vision when he is on the footplate, and they are so brilliant that they catch his eye and attention very quickly both by day and night.

Practically, the use of Light signals reduces the number of aspects he meets with at a signal post to one aspect at a time. This in itself is a great advantage, as the same light without any alteration can be seen both by day and night.

The four-aspect system provides for fast, medium and slow speed working on the same line, and allows the trains to keep moving as long as there is sufficient space ahead for the trains to go safely.

Then, under this system, a fast-running train receives two cautions or a warning and a caution before it reaches a signal exhibiting a Red light, which is a Stop signal. This double caution enables a driver to run at speed with more confidence and reduces the risk of over-running the signal.

The lights used are concentrated by suitable lenses and pass out of the front of the lens in the form of parallel rays, forming a beam of great brilliancy, and a beam at a suitable angle to the main beam, generally known as the « side light ». This is necessary, as the light in the lamp is placed in the focus of a lens and passes out as a beam of nearly parallel rays, which cannot be seen when a driver is quite close to or by the side of the post, but if a suitable side light is provided the driver can come up to a position quite close to the post and as the main beam goes out of his view, the side light comes into his line of sight so that he can see the signal aspect distinctly even if he is by the side of the post. Keeping the light signal aspects low down, so as to be in the line of the driver's vision, helps considerably to keep the main beam more nearly in the driver's line of view until he gets quite close to the post.

The difficulty drivers have to see signals during foggy weather is only too well known. On the District Railway, Fog light repeater signals placed about 100 yards in front of the Stop signals are being used and are switched on by the signalman when the fog commences. These are much appreciated by the motormen and drivers. The question arises whether when these brilliant lights of the signal aspects are used it will be necessary to provide these additional White light Fog repeater lights; it is hoped that it will not. In a medium fog, a light signal aspect can be well seen 200 yards away, but it is obvious if the fog is especially dense it is very probable that the light in the Fog repeater or in the Signal Aspect will not be seen until the driver gets within 30 or 40 yards of it. But in such a fog as this, a driver, for other reasons, would slow down or reduce his speed, and the four-aspect light signals he has just passed have given him two warnings.

If the Light signal proves satisfactory in a fog, the necessity for Fog Signalmen would be avoided.

Much the same difficulty is met with in long tunnels, and even just as he is coming out of the tunnel he often cannot see the ordinary semaphore arm or signal light, owing to smoke. Experiments in

tunnels have shown that a lamp with three beams, either White or coloured Red, Green or Yellow light can be seen, even with the very dense smoke met with in practice, for a distance of 30 yards before reaching the signal in the tunnel, using electric incandescent lamps as the source of light — a 24-C. P. focus lamp, 14 volts, current about 1.25 amperes, approximately 17.5 watts. The candle-power in the beam may be over 1 000 C. P. It is so that the whole area around the white or coloured light for 30 or 40 yards of the tunnel is illuminated when the area is filled with smoke.

The most convenient source of electric supply is a 220-volt alternating current, as the voltage can be transformed down to 14 volts, easily.

On the Southern Railway, for running signals, a lens 8 inches in diameter is used; for auxiliary signals the lens is 4 inches in diameter and for a shunt signal a 2-inch lens has been adopted and a sufficient distinction between the lights themselves is given.

With a four-aspect system of Signalling you cannot use Repeating Signals as understood in the case of ordinary semaphore signalling without a driver being allowed to pass a Red light, which the four-aspect light system is designed to avoid, so in the few cases where this class of signal will be required under a four-aspect Light signal system an auxiliary signal with three aspects, Green, Single Yellow and Double Yellow with a distinguishing plus sign or St. George's Cross on the top has been decided upon, it being arranged that the St. George's Cross is White on a Black background which will be illuminated always, but the principle of the four-aspect system will be maintained and the indications given on the auxiliary signal will be equivalent to those that would be exhibited in the lamp of the light signal at the next signal behind, were the driver approaching it. For instance, if a driver passed a Single Yellow aspect, then at that moment the next signal ahead would be the Red aspect. Suppose that it was necessary to give the driver preliminary warning of the condition of the signal ahead before he came to it, owing to the sighting of the signal not being good, and an auxiliary signal was installed; then the aspect exhibited would be a Yellow light under a White cross. If the conditions ahead remain the same, the Red aspect will be maintained as the train approaches the signal but the driver will pass the auxiliary signal : Yellow aspect with the White cross above it; but suppose the signal aspect has changed to Yellow, then the auxiliary signal will exhibit a Double Yellow with a White cross above it. Had the signal aspect changed to Double Yellow, then the auxiliary aspect would show Green with a White cross. If the signal aspect was Green, then the auxiliary aspect would be Green also.

The principle here is that the driver is given an indication of the condition of the road ahead both at the signal aspect he has passed and at the auxiliary aspect at the moment he is passing each of them. When the driver passed the signal aspect, the conditions of the road called upon him to be prepared to stop at the next signal and if the signal aspect ahead remained Red, then the auxiliary aspect, a Single Yellow, tells him again to be prepared to stop at the next signal, but as a White cross is exhibited above the Single Yellow, which is also a smaller light, he knows he is passing an auxiliary signal and, of course, he is running under the instruction of the signal he last passed.

It is proposed that the Normal Aspect of the Auxiliary Signal shall be the White cross only and this Normal Aspect will be exhibited only when the rear signal aspect is showing Red. This will avert any chance of a driver standing at a Starting signal seeing a Signal Aspect

ahead that would conflict or be different from the Signal Aspect he is stopped at.

It is anticipated that with the four-aspect system of signalling the Auxiliary Signal will only be very seldom wanted.

This method gets rid of the necessity of a driver passing a Red light on any occasion, a result which we have all been trying to attain for many years.

If it is found necessary to use this class of signal aspects in case of Fog « Repeaters », the auxiliary signal aspect will be used, with the exception that a White letter F, brilliantly illuminated, will be used instead of the White cross in the top auxiliary signal, but as I have mentioned above, it is hoped that the provision of those Fog Repeaters will be unnecessary.

It will be seen that this auxiliary signal does not in fact repeat the signal ahead or that behind, as the latter goes to Red immediately the train passes it, and if the former remains at Red the auxiliary aspect is Yellow, so it is necessary to provide a name nearer to the actual function and « Auxiliary » Signal seems the most appropriate and has been adopted on the Southern Railway.

The principal advantages of Light Signals are :

1) The same aspect is displayed both Day and Night;

2) They are definite. There is no question of drooping arms when an aspect is exhibited; — it is distinct and definite;

3) Owing to its smaller size, it can be brought down in a position in a line with the driver's eye, as the gauge will allow;

4) There is no moving mechanism and drivers always see the aspects only;

5) The track is kept clear of signal wires;

6) They are economical in maintenance;

7) The aspects are brilliantly displayed and easily seen;

8) No Red or Stop light has to be passed.

The difficulty experienced by a driver in determining the nature of the Distant Signal as he approaches it is minimised by the use of the fish-tail semaphore arm during the day, and, on some lines, a distinguishing Distant light or two strips of White light by the side of the Red or Green signal light; but the practice of providing Yellow semaphore arms with fish-tail ends during the day and Green and Yellow lights during the night is being introduced and is considered an advantage over previous practice but it is only applicable to the Semaphore System of signalling.

The use of long-burning paraffin oil lamps for signals is now almost universal. The light given is concentrated by means of a lens into a beam of parallel rays which has to be directed as nearly as possible in a line with the driver's view, but often, owing to the Signal aspect being so high, a repeater of the signal has to be fixed on the post about 14 feet from ground level. Practically in all cases where the signal aspect is 35 feet or over above the level of the ground, a repeating arm is provided. This is costly, as two lights have to be maintained. It is often a question whether such high signal posts are required. The lower the signal aspects are placed, the more clearly can the drivers see them.

The signalling at junctions is a vexed question and the present practice results in such cases as I mentioned at Bricklayers' Arms Junction, where a driver meets with seventeen different semaphore aspects when he runs up to the signal post and seventeen different light aspects during the night; and even in Light Signalling, if present practice is followed, as it seems probable, there will be a multiplicity of four-aspect signals side by side, some at lower levels than others. The alternative to the present system is

to provide one four-aspect Colour light signal and a route Indicator above it, or in some convenient position relative to the light signal. The driver has then a very simple signal to guide him. He sees the Green, Yellow or Double Yellow or Red light distinctly and the route indicator, as it is as equally brilliantly lighted as the Red, Green or Yellow aspect. But the objection is raised that the driver cannot read the route indicator so far away as he can see the Light Signal aspect. It hardly seems necessary that he should for practical working, but if it is arranged that he sees the indications of the route indicator, say, 200 yards before he passes the signal, that should, in my opinion, be sufficient for all purposes. If that is agreed, a much simpler signal aspect is exhibited to the driver, and this simplification will add to the efficiency of the signal immensely compared to the case where a multiplicity of four-aspect signals are exhibited. The route indicator on Light signal aspect is more definite than a multiple four-aspect signal : 1) a four-aspect for the main and 2) another for the branch.

It is agreed that the principle of route indicator on semaphore and four-aspect signals is suitable for Starting or Home Signals where the speed is slow, but not at junctions. The question seems one for discussion.

It is necessary that the drivers should themselves see the signal aspects, but in numerous cases of accidents the excuse has been that the driver did not himself see the signal and there had been some misunderstanding between him and the fireman who did see it. Generally, in such cases, the driver is driving from the right side of the engine, whilst the signals are placed rather to the left of the engine. There is a tendency to bring the drivers to the left side of the engine for driving but it is very desirous that the practice of the driver driving from the left-hand side of the engine should be universally adopted, especially now the speed and density of trains have increased so greatly.

Track circuits are very useful, as they provide means whereby the trains automatically control the signalling safety devices put in to prevent collisions and accidents, but this operation is entirely prevented by sand being deposited on the surface of the rails. I am sorry to say there have been too many failures of the track circuits due to this sanding and when it is considered that this sanding results in the indication to the signalman being that the road is clear whilst it is occupied, it is obviously a serious matter, as it is a false « Clear » and the signalman may be misled by it. If anything can be done to avoid or minimise this difficulty, the efficiency of the track circuits and the safety of the traffic will be increased. It will be easily seen that the correct operation of the track circuits is of great importance to all sections of the Railway, including the Locomotive and Signal sections.

Various systems of speed signalling have been proposed and in some cases adopted in America, but the number of aspects necessary to give the desired information to the driver are so many as would be likely to confuse him. In one case fifteen different aspects and in another as many as twenty-seven different aspects are required to indicate to the driver the speed he should travel over the section of the line ahead. This is, of course, very complicated and the mechanism to operate it is not simple : certainly not so simple as with the four-aspect signal I have described above, which leaves the question of what speed he shall travel in the hands of the driver, and it is generally agreed that this is the better system to adopt. Certainly, when the responsibility is with the driver, he is more likely to deal with an emergency more promptly than if he took instructions from the signals as he was running.

Automatic train control.

The question has often been raised as to whether some check cannot be imposed on a driver so as automatically to prevent him disobeying the indication of the signal, much in a similar way as a signalman is checked by the Sykes Lock and Block System, or by the mechanical locking in the signal frame.

On the Underground Railways where the trains are all practically alike and the maximum speed is not high — about 35 miles per hour — the Train Stop System has been in use for many years; but this system is not altogether suitable to surface railways where trains run at 70 or more miles per hour.

It has frequently been put forward that the necessities would be met if the signals were repeated in the cab of the engine. To do this would be very costly, and a cab signalling system has the great disadvantage that the driver has to, or in fact will, concentrate his attention on the cab signalling indicator if, not all the time, during a large proportion of the time, which should have been given to watching the state of the road ahead. Further, it is still left to the driver to obey the signal given by the signal in his cab as he is at present to obey the outdoor signals and he is just as likely to mistake the one as the other. The general feeling that this is quite insufficient is confirmed by the report of the Ministry of Transport Committee on automatic train control. If anything that is effective is to be done, it must be something that will stop the train, should the driver pass the signal when it is in the « on » or Danger position.

To establish complete automatic train control of a simple kind over the whole of the railways in Great Britain and Ireland would, it is estimated, cost approximately £5 000 000 and the Annual Maintenance would, it is estimated, be £500 000; all this is additional to the present maintenance costs.

The number of collisions during 1924 — the latest date the returns are available — due to drivers passing signals in the « on » position was three. There are 38 180 engine drivers; — one failure for every 12 727 men.

There were three collisions due to enginemen failing to give effect to Regulations or misjudgement and five due to divided responsibility — take the whole eleven as applicable to drivers, then there was one collision to every 8 289 men per annum. A driver it may be taken, travels 130 miles per day for 326 days of the year. There is one collision due to drivers for every 138 960 000 train-miles run. Whichever way it is put, the number of preventable accidents that can be avoided by the introduction of automatic train control is small. However, the number of passengers killed on railways due to collisions during 1924 was 10 and 428 were injured, so that this is an appreciable and serious figure and has to be set against the cost of automatic train control.

The small number of collisions shows the high degree of efficiency of drivers and the care they take, and as I have previously pointed out, to increase this efficiency it would need a perfect system, as with the multiplicity of apparatus and mechanism, which is liable to accidents in a similar way to all other mechanism, the number of failures due to the additional mechanism introduced may easily be appreciable.

Automatic train control on Surface Railways has not made much progress in this country recently, no doubt due to : 1) the small number of accidents that could have been prevented; 2) the enormous efficiency of the driver, and 3) the enormous cost to instal a complete scheme covering the whole country.

The principal systems in use in Great Britain to-day are :

1) The Great Western Railway system

of Warning at the Distant Signal : it is an intermittent Electro-mechanical system;

2) The Reliostop system on the Great Central Railway section of the London & North Eastern Railway which is an intermittent system; — that is, the control is exercised by ramps placed at certain points of the line. It gives a Warning application of the brake at the Distant and an Absolute Stop at the Home or other Stop signal;

3) The « Syx » Electro-mechanical system of Warning at the Distant signal; — it is an intermittent system;

4) The Mechanical system on the North Eastern section of the London & North Eastern Railway.

A number of other systems have been tried on various lines but have not been adopted.

I do not propose to describe these systems as they are so well known, but it may be interesting to consider what is being done in America where forty-five different railways have been ordered to instal automatic train control over a division of their railway by the Interstate Commerce Commission, only four railways in the United States being exempted from making the experiment.

Fifteen railways have completed their installation and most of the others have nearly completed.

There are thirteen distinct systems, some having various modifications, making eighteen different systems :

		Number of railways on which applied :
American Train Control Corporation		1
G. R. S. Coy.	Intermittent system.	12
	Two-speed continuous	1
	Stop.	1
	Three-speed continuous	1
Miller Train Control		1
National Safety Appliances Company.		5
Regan Safety Device Company		1
Sprague Safety Control & Signal Corporation		4
Union Switch & Signal Company	Two-speed continuous	7
	Three-speed continuous	4
	Intermittent	2
	Stop.	6
		46

Automatic Train Control has been ordered on 7 733 miles of track :

Miles of track completed.	1 595.8
Miles of track under construction.	3 839.1
Miles of track commenced or about to be.	309.6
Total mileage completed or under construction	5 744.5

Of the 232 013 track miles of railway in passenger service in the United States of America, 40 % is not protected by signals at all, and 7 733 miles is 0.033 % of the whole length of passenger lines.

It is a grand experiment, but very costly, and the fact that there are so many different systems is a disadvantage, but no doubt a process of elimination will take place and the best survive, but for simplicity and uniform operation it is to be hoped that one system will be finally adopted.

The following figures of the actual cost of the appliances and the installation of the systems are very interesting. It will be seen that the cost per mile of an intermittent system something like that

installed on the Great Western Railway is approximately £4 276 and for a system under which the train is continuously automatically controlled the cost per mile is £4 820.

A calculation shows that to equip the 20 329 miles of Railways in Great Britain at these rates would be £86 926 000 and £98,987 000, respectively, about twenty times the estimated cost already given. Probably the labour and other charges are much higher in America than here.

Miles of railway equipped.	Total cost.	Cost per mile.
—	£	£
84	395 720	4 711
58	238 830	4 104
340	1 426 025	4 013
130	255 850 (1)	1 968

(1) Partly equipped with automatic.

Cost per locomotive	£650
Cost per mile of wayside apparatus and labour.	£2 888
Cost per train stop	£405
Average total capital cost per mile of railway to instal an intermittent, or what is called « The Stop and Forestaller » system	£4 276
Average total capital cost per mile of railway to instal Continuous stop and Speed Control system	£4 820

There are 20 329 miles of running routes in Great Britain : taking the American cost as a basis, to equip completely the running lines of the railways in Great Britain would cost for :

Intermittent system	£86 926 704
Continuous system.	£98 785 780

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Investigation into the principal causes of railway accidents,

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Figs. 1 and 2, pp. 731 and 732.

(*Les Chemins de fer et les Tramways.*)

The attention of the public has once again been called to the risks inseparable from the movement of traffic by railway by the accidents that have recently occurred at short intervals on several of the principal French railways.

These untoward events have had the greater effect on public opinion, as for some years attention has not been directed towards this question. The preceding years were not marked by any serious accident, and this period of calm following the troubled years from 1919 to 1921 had led people to think that the danger of such accidents occurring had been almost removed.

This recall to sad reality should not, however, lead the public to think that no real progress has been made during the last five years in railway operation. It is desirable, though, that accidents be appreciated at their full value, and especially that they be fully investigated, and it is this that we intend to do in this present examination.

First of all it should be noted that investigations into the causes of accidents are much more intricate than would be expected beforehand. An ac-

cident is actually the result of the combination of one or two principal causes, dangerous in themselves, with a number of secondary conditions frequently impossible to determine, and which can not be avoided separately.

It is consequently useless to look for any direct relation between the existence of any such cause and the number of accidents resulting therefrom.

Even more so than in other questions, statistics relating to accidents are misleading, and we should avoid making any use of them.

The enquiries constantly being made into accidents, of which the public hears nothing, have often shewn that all the conditions under which an accident could happen have been present, either without an accident occurring, or, at least, without the serious results that might have been expected.

In some cases the presence of mind of an employee has prevented a collision, in others the fortuitous putting to danger of a signal has stopped a train before it reached some obstacle on the line, or, the unusually late running of a train has avoided a collision.

It is therefore important that really dangerous causes should not be confused with conditions, which it would be useless and sometimes even undesirable to remove. Unfortunately the press, although lacking information about the details of the problem, frequently concentrates on these secondary causes of accidents, and, by its undeniable influence with public authority and the control service, sometimes is responsible for the steps taken to prevent their recurrence missing their real objective.

Having said this, we will now briefly consider the different kinds of accidents, point out the fundamental causes and suggest the remedies that should be taken. We will then examine those features common to all accidents, and the measures, in general to be taken to reduce their number, and especially their seriousness. Without going any further into the matter we can definitely state that, so far as the safety of the passengers is concerned, such general measures are much more effective than any particular safety precaution.

Railway accidents can be classified under two main groups :

1. — Derailments caused by one or many pairs of wheels leaving the rails;

2. — Collisions due to trains running into some obstruction on the line.

Derailments.

Derailments were formerly the most frequent of accidents, so much so that the public were accustomed to describe all accidents as derailments. Thanks to the generally good state of the track of the principal Companies' lines, and to improvements in permanent way appliances that have been introduced, they are now much less frequent.

Derailments on running lines.

Derailments on running lines are almost unknown in these days.

Those accidents entirely attributable to the state of the track should only occur on lines carrying little traffic, as such lines are necessarily not so well maintained as the main lines. The consequences are fortunately much less serious as the speed on these lines is slower and fewer passengers are carried. Such accidents generally take place as the result of the displacement of the track on a sharp curve by a preceding train, for which poor anchorage of the track, owing to sand, earth or water-logged ballast, and also excessive speed, must be blamed.

As relaying is very costly in comparison with the small earnings of the line, it is most necessary that the speed of trains over curves of small radius should be limited. As it is, all neces-

sary speed restrictions have been in force for a long time, as we shall see below : the only difficulty is in seeing that they are observed.

Derailments have occurred on running lines and have been caused by the excessive oscillation (nosing, etc.) of certain engines. In such cases the remedy is to see that the maximum permissible speed of the engines in question is less than the speeds at which these oscillations become dangerous.

Modern locomotives are unlikely to cause such accidents as the critical speeds are higher than the highest speeds practicably possible. Derailments due to this reason are only likely to occur on lines with little traffic, and the consequences are never serious.

The failure of certain parts of the locomotive, or of the stock (such as axles, tyres, etc.) may cause derailments on running lines. Locomotives and carriages are so carefully inspected and maintained that accidents of this kind are not likely to happen. On the other hand, they do take place occasionally with goods trains as the goods wagons are not so carefully looked after and also have to stand the violent and frequent shocks to which they are subjected during shunting. As the speed of such trains is very low, the results of these derailments is even less serious.

Excessive speed through points and crossings.

The points and crossings are the weak spots of the railway, and in spite of the care and supervision given them, all serious derailments take place when running through them.

The most usual type is that due to too high speed when being turned through points from one line to another, and has recently been illustrated by two accidents (Saint-Antoine du Rocher on the Paris-Orleans and Amiens on the Nord). It is easy to see that a train cannot safely pass such points at high speed : for one thing, the line from being straight suddenly becomes sharply curved and owing to the inertia of the train the first wheels endeavour to continue to travel straight forward and their flanges tend to mount the rails : on the other hand, as the turnout is from a line on the straight, no superelevation is possible so that the centrifugal force tends to throw the train outwards. Furthermore, the pressure of the flanges on the outer rail is considerable owing to the inertia effect, and tends to deform the points and may even displace the heel of the point.

Finally, the shocks to which the wheels are subjected when passing through the crossing tend to assist the flanges to mount the outer rail.

The principal Companies limit the speed through turnouts to 24.8 or 18.6 miles an hour. Attention is called to the speed reduction on the site by warning signals placed 1 100 yards before the points. As a result of the two last accidents (Collonges [Paris-Lyons-Mediterranean] and Saint-Antoine du Rocher [Paris-Orleans]) the railways have been ordered by the control service to put down « ramps » operating repeating signals in the cab.

Such speed restrictions are a simple method by which derailments may be avoided, but many practically minded people desirous of making progress, have pointed out that they are not a real solution of the question, and that they are also very costly.

Important junctions are, as a rule, near busy centres — and may be situated in flat or hilly country. In consequence, to reduce speed when passing these junctions involves a relatively important loss of time, amounting to as much as 5 minutes for the express trains, as such trains take a long time to regain on the banks the time lost by reducing speed. All time lost means increased consumption of fuel.

For these reasons the suggestion has

been made that points of small angle in which the two tracks have equal curves of easy radius, but in opposite directions should be used.

Such points have been in use for many years on several of our principal railways, and allow trains to go in each of the two directions at speeds of 37 and even 50 miles an hour without any undue shock to the carriages, and without in any way deforming the points themselves.

This arrangement, however, requires very strong construction so that it is not likely to be deformed, and also has to be very carefully maintained to make good wear and the results of repeated shocks.

Owing to the very sharp angle formed by the two rails of the diamond, the passage of stock through such points is easily upset; nevertheless the increase in speed obtained with such an arrangement fully justifies its use and has the advantage that the drivers can be made to observe the limits of speed in force.

Split points.

Although frequent formerly, derailments due to split points are now rare. If the nose of the point is not firmly held against the stock rail, the point rail can open. The wheels try to follow both tracks until they mount the rails and drop on to the sleepers across both lines.

This movement may be due to play in the operating gear, or to some object, usually a stone on one of the sliding plates of the point getting in between the point rail and the stock rail.

Careful inspection of the points will prevent such cases, but as the inspection may be neglected, a control device has been introduced. By failing to make electrical contact the signalman is warned either optically by a moving disc or acoustically by a bell ringing that the heel of the point is not home.

The accident (Coutras on the Paris-Orleans, 24 August 1907) shewed that these precautions were unfortunately insufficient, as they did not compel the signalman to act in accordance with the indication they gave.

The system was then perfected by adopting the « Contrôle impératif » in accordance with which the control circuit is interlocked with the signals protecting the junction so that the signalman can only give the road if the points are in the proper position.

The arrangement in some cases also calls attention to the failure of certain parts of the points and crossings.

As it was not altogether satisfactory, enquiries were made to see if some method could be found which would give warning of all such breakages, and in particular of that type of moveable point in which the point is not solidly attached to the operating lever but can move under the shocks due to wheels running over it.

An early method was to lock the points so that they could not be reversed and to interlock the levers operating the locks with the signals covering the points.

The accidents at Artix (Midi), 23 August 1919, and Reims (Est), 21 January 1922, shewed that this was not enough, and the design of the points was altered so that two parts had to break before they could be put out of action.

Since these precautions have been taken, no derailments due to this cause have been reported, although they were frequent in the past.

As a matter of interest should be mentioned derailments due to broken rails, which are now very infrequent, as on the principal Companies' lines the rails are renewed in good time and are under constant observation and those due to the distortion of the track through expansion (Beaucourt-Hamel, Nord, 25 June 1921) which can be avoided by leaving sufficient clearance between the rails without affecting the steadiness of the

stock so long as the joint sleepers are kept properly packed up.

Collisions.

Unlike derailments, there has been little relative reduction in the frequency of collisions since the beginning of railways in spite of the continuous efforts ever since made to prevent them. The increase in traffic and the faster speeds counterbalanced the efforts made in this direction, at any rate until about 1910.

Under the heading collisions have been included the true collision of two trains meeting when travelling on the same line, and also those caused by trains on different lines running into one another. The two kinds have been brought together as the results are the same in each case. We will, however, consider them in turn in order to examine the causes.

Collisions of trains on the same line.

This sort of collision ought to occur more frequently between trains meeting on a single line than between trains going in the same direction. Two trains meeting approach at higher speed than when going in the same direction, so that the risk should be much greater in the former case. In practice it is not so as the density of traffic on single lines is much lower than on double track lines, and the mean speed is in consequence much lower owing to the few fast trains run, and because the line usually has heavier grades. Thirty years ago collisions on single lines were fairly frequent, and the Companies introduced all sorts of protective devices (staff, electric staff, etc.) which cannot be described in the limits of this article. These measures and very detailed regulations strictly enforced rendered collisions on single lines very infrequent. They had the disadvantage, however, of seriously limiting the capacity of the line.

The Paris-Orleans Company, wishing to increase the traffic over the Limoges-Montluçon section used by the Bordeaux-Milan Express amongst others, replaced these methods by the train dispatching system. The results obtained in the last two years have been most conclusive. The traffic handled has greatly increased, and the delays been markedly reduced, without any accident having occurred.

Another interesting method is the electric train staff used in America, and which is an improvement on the ordinary staff in use.

Attention should also be called to the tests made by the State Railways of the block system on the single lines between Trouville-Deauville, Dives-Cabourg, Pont-du-Cher and Joué-les-Tours. The instruments have been in use several years and have given every satisfaction, whilst the traffic handled has been appreciably increased.

However, the traffic over most single lines cannot be developed to any great extent, and therefore the Railway Companies are unlikely to be willing to spend the money necessary to equip them in any of these ways.

It is necessary, therefore, that the inspectors should see that all regulations for safe working are carefully observed as the staff, if left to itself and not in contact with the danger in question, is liable to neglect them.

Double lines.

Collisions between trains running in the same direction on lines used for trains in one direction only is the most frequent type, and the one that has been most carefully looked into.

In order to prevent it, the problem is to keep the line clear in front of and behind the train for such a length that any train can stop in it. To solve this it was thought that trains should be spaced at time intervals, *i. e.*, a train should not be allowed to leave a station until a certain time, generally 10 minutes, had elapsed after the passage or departure

of the previous train. This arrangement implied that if the train was stopped outside the protecting signals, the rear guard should hasten back and protect it by stop signals (flag or red light) at a distance of 1 100 yards, placing detonators on the rail to warn the driver of the following train by detonating that there was agreed that 10 minutes would be enough for the guard to protect his train, taking into account the time lost by the train stopping.

When the question is examined in detail many difficulties arise : different speeds, time lost by the first train, thereby allowing the second to be less than 10 minutes behind, etc. A host of regulations has been issued to overcome these difficulties, in spite of which the system never gave sufficient security, and for it has been substituted on most double track lines the « block system » whereby the movement of trains is controlled by distance and not by time intervals.

Block system.

The block system consists essentially in dividing a portion of the line into a number of sections, varying in length with the traffic on the line, and refusing to allow a train to enter a section so long as the preceding train is in it. A description of the different block systems would take too long and would justify a complete paper on them alone. We will only give the essential features.

Telegraphic and telephonic block system.

The simplest block system, but which is also the least safe, is the telegraphic or telephonic block, under which the stations or signal boxes simply notify the next box when a train has passed. The serious defect of this system is that it depends upon the rectitude of the staff, as it provides no means for checking their statements. It is only suitable for lines with little traffic, and in practice is only rarely of use as the trains are usually sufficiently far apart. Furthermore, the Companies, taking into account the little extra security it gives, continue to require the trains to be run with sufficient intervals of time between them.

Mechanical and electric block system.

The real block system is that in which the giving of line clear is subordinated to the home signal of a section behind the train which has just left it being put at danger, and the lowering of the signal to allow a train into a section, to line clear having been given by the section in front.

The block is absolute if no exception is allowed to these rules and permissive if a train is allowed into a section before line clear is received, either on arrival at the beginning of a section or after a certain lapse of time (5 or 10 minutes).

In the latter case the line is cleared more quickly, but some uncertainty may remain in the minds of the signalmen who have allowed several trains into a section when they receive line clear. It has therefore been necessary to make various complementary arrangements to ensure safety, and to continue to require the rear guard in case of a stop outside signals to protect his train.

The defect of most of the block systems is that there is nothing to prevent a signalman from putting the signal to danger before a train instead of behind it, thereby giving line clear to the section behind. This not only allows the preceding section to send a second train forward, but, still worse, prevents the first from leaving the section, and thereby avoiding the collision. This result has happened fairly often, especially at night when a train has been stopped between two boxes for some reason or other (such as brake failure, alarm signal acting). The signalman, who has been

asleep, is suddenly wakened by the telephone bell ringing, and the preceding section asking if the train in question has passed as the next train has been standing at his box several minutes — a very unusual occurrence. The signalman realising he has been asleep assumes that the train has passed whilst he was asleep, puts his signals to danger and gives line clear. It is probable that the recent collision at Sens (Paris-Lyons-Mediterranean) occurred in this way, although it was never proved that the signalman had been asleep.

Semi-automatic block system.

Most of the principal Companies have met this danger by requiring the rear guard to protect his train 1 100 yards in the rear, should it be stopped outside the protection of signals. The Sens accident shewed, however, that this precaution might be insufficient if the detonators failed to detonate, and if the driver of the following train failed to see the red flag or light shewn by the guard.

Several of the companies are considering whether this danger can be completely removed by interlocking the giving of line clear with an electric contact placed at a distance from the signal box equal to that of the longest train likely to be worked. This is the semi-automatic block particularly used on many lines of the State Railways.

Degree of confidence to be placed in the block system.

In spite of all these improvements, care must be taken not to place absolute confidence in block system instruments, operated by signalmen.

It is hardly an exaggeration to say that whatever care may be taken to prevent a signalman giving line clear when his section is still occupied, the signalman working the same instruments year in and year out will in the end find some way in which he can get round the regulations. These « tricks of the trade » discovered by the more intelligent men are secretly passed on to their fellows, and the safety of working is thereby reduced.

Until recent years there was more or less general confidence in the block system instruments in spite of the fact that a number of unexplained accidents had given rise to some doubt in the minds of many railway technical officers. The enquiry held immediately after the collision in Batignolles tunnel (French State, 5 October 1921), which was completed only after a most patient investigation, definitely established that it was possible to misuse a block system, considered thereto as foolproof. The Companies were in consequence obliged to insert in their regulations an order that no alteration to the interlocking gear was to be made.

Whereas interlocking had been introduced originally to strengthen by mechanical means the regulations issued to the pointsmen, it now became necessary to restore the moral obligation. This proves beyond doubt that the essential factor for safety in working lies in the professional conscience of the men.

Automatic block system.

It will now be evident that complete confidence can only be placed in those instruments which are completely automatic, and operate without any one's assistance. The Companies appear to be moving in this direction with a view to reducing the risk of collision, beginning naturally with sections carrying the heaviest traffic.

The French State Railways have fitted three suburban sections with the automatic block, using track circuiting, and the results obtained have been entirely satisfactory from every point of view. The installation has been so arranged that in case of failure of any part, the signals go to danger.

The results obtained by the Metropolitain and Nord-Sud Railways are very convincing, as, in spite of the very intense traffic on these lines, there has never been a single collision.

In spite of the saving of staff obtained, any great extension of the automatic block system in the years to come is improbable, owing to the very heavy costs of installation.

Observation of signals.

However perfected the block system instruments may be, and whatever degree of confidence be reposed in them, they will be useless unless the drivers observe the signals and obey their indications.

The observation of signals is a matter of capital importance in railway working, and has frequently, and rightly so, occupied public opinion as well as the control services.

Whether they be block signals or signals protecting a station or a junction, they are of two kinds : stop signals (semaphores and square signals chequered red and white) and the distant signals (red signals and warning signals in green and white check). As previous warning is given of the former, there should be no difficulty is sighting them. As distant signals may for various reasons fail to act, as the accidents at Saint-Jory (Midi, 4 September 1919), Châtelaudren (French State, 29 October 1922) have shewn, it is important they should be placed so that they can be seen from a considerable distance, as well as at sufficient distance from the point they protect in the case of square signals to give some margin of safety.

With these objects in view, the control service has recently ordered the re-sighting and improvement in visibility of all stop signals even when preceded by warning signals.

The observation of distant signals is a more delicate matter, and the efforts of the control and of the Companies have since 1919 been devoted principally to this question.

The first thing thought of is to place them so that they can be seen from as far off as possible. The control has prescribed that they shall be visible during at least 10 seconds at the highest speed a train may be running at the place. This is not enough. Experience has shewn that in fog or snow, and especially by night, the signals may be visible for only 11 yards or so. The drivers have first of all to know exactly where they are placed on the line relatively to sighting points of their own choosing, and then to give all their attention to sighting them to the neglect of their engine. Should anything go wrong with the engine, the driver may look round to see what has happened and pass the signal without noticing it was at danger.

Remedies to overcome these defects have been thought of, by warning the driver he is approaching a signal, as for example by painting the telegraph poles preceding each signal white. This method has been found really useful.

A more complete solution of the problem is required, however, and this has been found by making use of the sense of hearing which is much more alert than the sense of sight. When a signal is passed at danger an electric circuit is completed by a flexible metal brush on the locomotive coming in contact with a ramp in the track, which operates a whistle of special tone thereby calling the driver's attention to the fact that he has passed the signal. This arrangement has been in use on the Nord for a very long time and is now being installed on the other Companies' lines. Following the accidents of Pont-sur-Yonne (3 November 1919) and Perrigny (5 February 1920) the control has compelled the Companies to install this arrangement in spite of its cost. There is no doubt that they have rendered considerable service and prevented many accidents. They

are rather delicate to keep in order and have to be constantly watched. So far, it has not been found possible to avoid defects in operation. The Companies have therefore warned their drivers not to place too much confidence in them and require them to make the agreed mark in the speed indicator diagram when they see a signal at danger, so as to oblige them to sight the signals just as though they were not repeated acoustically.

It is none the less desirable that these appliances be perfected and their use extended to cover caution signals. If anyone fears that some confusion as to the kind of signal met at danger might be caused thereby, it should be remembered that every signal at danger necessitates a reduction in speed possibly followed by a stop. Any driver afraid of having mistaken the signal has only to conform to the indication given by the most important signal, the red disc stop signal.

Installation of a lookout on express locomotives.

As a result of recent accidents, as in the case of all serious accidents due to non-observance of signals, well-intentioned people, not versed in railway practice, have suggested an additional lookout man on express engines in addition to the driver and fireman, whose sole duty would be to take the signals and watch the line. It is not easy to see where this man would be placed, as the driver's seat in a modern locomotive is the only place from which the signals can be easily seen owing to the length of the boiler and its large diameter. It is also difficult to see what there would be left for the driver to do when things were normal, as he need not move from his post, all he has to do being to open and shut the regulator and to operate the brakes. He has therefore little to do on an express, as there are few stops. He has therefore plenty of time to watch the signals. It may be objected that in practice the attention of the driver is frequently taken from watching the line by the boiler not steaming well, or by certain fittings, such as injectors, not working properly. The remedy is simple and much cheaper than providing a lookout. It consists in giving the express train engines good coal, keeping them in good order, and seeing that their firemen are skilled. It is also important that the timing of the trains should not be too fast nor the loading too heavy for the power of the engine.

Obedience to indications given by signals.

Attentive observation of signals is useless unless it is followed by action in accordance with the indications given by them, which brings us to the question of brakes.

The distance of 1 100 yards which normally separates a distant signal from the home signal concerned is amply sufficient in the case of trains fitted with continuous brakes, to enable them to be stopped even when running at maximum speed.

The only point that arises is the proper working of the brake, and this depends upon the continuity of the train pipe throughout the train.

Almost all accidents attributed to defective brakes are due to the shut off cock being left shut between coaches, or, what is even worse, between the tender and the front brake van.

For this reason too much care cannot be taken in seeing that the tests of the brake required by the regulations are properly carried out before the train leaves, and again at each station where the make-up of the train is altered.

In the case of trains not fitted with continuous brakes, the subject is more complicated owing to the many factors which have to be considered : brake power of the engine, maximum gradient to be encountered, efficiency of brake

gear, loading of wagons, maximum speed, etc. Great improvement has resulted from the general application of the regulation fixing the brake power in relationship to the weight during the last few years on all the principal Companies. The regulations have rationally determined from the steepest gradient, the highest speed allowed, and the brake power of the engine, the minimum weight of wagons on a train to be braked. The coefficients used have taken in account some of the unfavourable conditions which might affect the stopping of the train : insufficient adhesion between the wagon wheels and the rails, time taken for the brake to act, wear of brake gear, etc. Unfortunately these regulations do not take into account, and it would have been very hard to do so, the difficulty the brakesmen experience in taking the signals given them by the driver.

The drivers have only the steam whistle with which to communicate with them. People not used to railway working will no doubt be astonished to learn that this should be so now that the telephone or wireless telephone is in constant use, but the fact is that so far no instrument sufficiently robust to stand up to ordinary use and be reliable in working has yet been brought forward for this purpose. A goods train forms, it must be admitted, a very searching test bench. It is not less certain that the steam whistle is far from satisfactory : it has been found by test that, on a train running at 31 miles per hour, a brakesman who has not previously been warned, and is shut in a brakesman's shelter, cannot hear the whistle, however powerful and frequent it may be, if he is more than 40 wagons from the engine. As most of the brakesmen ride on wagons at the rear of the train so as to be able to brake the wagons in the event of the train becoming divided, and as many goods trains are now made up to 60 or 80 wagons, it will be seen that the driver can only count on the engine brakes and those on the few wagons fitted with continuous brakes, which are usually coupled next the engine, so as to reduce the number of brakesmen required. In the practice drivers skilled in handling such trains only ask the brakesmen for assistance in very rare cases, and this unfortunately weakens the attentiveness of the brakesmen previously, none too great, owing to the very uncomfortable conditions under which they work. If anyone asks why there are not more collisions with goods trains, the answer is that the brake regulations give a very good margin of safety, and the brakesmen brake the train on their own initiative for their own safety when they feel the train is running too fast, when descending long banks, when approaching a stop, and also when they feel the train buffering up through the braking of the locomotive and the wagons next it.

More powerful whistles might be provided, but putting aside the fact that the tests made for some years have not been successful, the use of more powerful whistles than those in use would certainly raise protests from every one living along the line, and reasonably so. Telephones could not, as we have seen above, be counted upon to work properly, and the heavy cost of fitting them could not be agreed to by the principal Companies. The only solution is to fit continuous brakes to the goods trains. Although this was done in the United States many years ago and with satisfactory results, the European nations have not yet decided which is the best brake to fit. The decision to be taken requires much reflexion in view of the financial consequences, and is not easy to come to, as the problem is so very complicated.

The problem of braking goods trains is much more difficult than in the case of passenger trains owing to their greater length, the variety of stock, and the differences in total weight of the wagons.

It is most regrettable that in spite of the very complete tests made in 1920 and 1921 to determine the best system of brake, no decision has yet been made, and still further tests are to be made in Switzerland.

In this way there is danger of losing the advantage given us in the Treaty of Versailles, whereby the Allies were able to impose on Germany the type of continuous brake they adopted, provided the choice were made within ten years.

Taking advantage of the Allies' indecision, Germany has already fitted a third of its wagons with the Kunze Knorr brake, and is working hard to fit the remainder with through pipes. It is therefore probable that even if a decision be come to within the ten years allowed, Germany will refuse to comply with it in view of the work it has already done. It is even possible that the work done in Germany may influence the experts in favour of the Kunze Knorr brake when the further tests are made, which would be unfortunate for our prestige abroad, as France has already decided upon the Westinghouse brake. However, the step taken by the Germans has been very well judged and is the best way of dealing with the difficult problem of braking goods trains. If the very heavy first cost of fitting the continuous brake to all wagons and the subsequent expense of maintenance are felt to be unjustifiably great, the German solution of fully fitting a third or quarter of the wagons, and the remainder with pipes only so as to do away with brakesmen, should be considered.

The only difficulties lie in distributing the « piped only » stock properly throughout long trains, and in getting drivers into the way of handling trains braked in this way. Neither is insoluble and needs only time and training.

Automatic train control.

A very attractive solution of the problem of getting drivers to obey signal indications lies in « automatic train control » invented and installed in America. The system consists in fitting the engines with electro-pneumatic gear, operated by a metallic brush in the engine, making contact with a ramp (as in the case of the repeating of signals on the locomotive) which operates the brakes as required by the signals. At least in theory the driver has no need to bother about signals any further, but can give all his attention to his engine, although, as we have already seen, in practice it requires very little attention really.

There should be much greater safety with this arrangement. Unfortunately as regards safe working the disadvantages, although apparently unimportant, present more sources of danger, as regards safety in working than the advantages remove. The apparatus is delicate and its working cannot be absolutely relied upon. The driver must continue to observe his signals just as though the automatic train control was non-existent as the gear may be out of order.

All train control appliances act by reducing the train pipe pressure, thereby applying the brake. These reductions cannot be graduated to suit the speed and load of the train, the profile of the line or the different braking power of the train, all of which the driver takes into account when applying the brake. As it is always necessary to arrange things so as to deal with the most unfavourable state of affairs, the speed reductions are generally too great and the stops too short. No such apparatus can have the skilled touch of the driver when applying the brake and certainly not when releasing it, especially in the case of a slack not followed by a stop. The use of the system may cause many breakages of couplings and thereby be a cause of accidents. In face of these drawbacks the drivers must be allowed the right to resume full control when necessary, marking with an agreed sign the speed indicator diagram in each case — just as with the

control handle of signal repeating gear.

The appliance would then only act when the driver had not seen the signal (this could be overcome by repeating the signals audibly in the cab), or if he could not work the brake. If a driver should suddenly become unable to continue his work, the regulations require the fireman to stop the train at once, whatever the position of the signals may be. The modified automatic control then would be inoperative just as its complete application dangerous. At present in spite of much advertising by American firms, no French line has yet undertaken to fit one of its lines, nor any of its locomotives, with automatic control apparatus.

Collisions due to breaking loose.

Accidents due to vehicles after breaking loose colliding with a following train should be included amongst the collisions. Although the causes are directly opposite to those of collisions properly speaking, the results are the same. Before such an accident can take place, the breaking of the coupling must occur at a place which will allow the rear portion to run back before it can be stopped and before it can be subsequently protected against a following train. It should be noted that accidents of this kind have occurred in which the whole train ran backwards (Mielan, Midi, 1 August 1922 is an example), the engine having slipped and the brakes having been unable to hold the train. Such accidents are fortunately rare, and can be avoided by seeing that the load is not greater than the engine has sufficient adhesion to haul. Now that the strengthened 70 t. couplings have been generally fitted, the number of broken couplings, one of the most frequent causes of collisions by running back after breaking loose, has considerably lessened. The strengthened coupling was ordered to be fitted as a result of the serious accident at Houilles (French State, 10 October 1920). Such accidents are very unusual when running: at starting or stopping the consequences should not be serious as the brakesmen are quick to notice anything of the kind. They are only to be feared in tunnels where the rails are greasy and engines slip frequently and in such circumstances it is not easy to notice when a train has broken loose.

With this exception the regulations laid down by the control, and adopted by the Companies many years ago, dealing with trains that have become divided, have resulted in the stock that would have run away being stopped immediately the break-loose occurs. These regulations take into account most of the factors that affect the question: maximum gradient to be met, efficiency of brake rigging and the time the brakes take to act, etc. They also allow a large factor of safety.

Collisions with buffer stops.

The last kind of collision is that against buffer stops at the end of a dead-end road. No serious accident of this kind has happened since the one at Montparnasse Station when the engine after demolishing the buffer stops ran through the station and fell into the road. For some time attention has been called to this kind of accident, as there has been a number of slight accidents, in all of which many passengers have been hurt, largely as the result of their habit of standing on the footboards a few seconds before the train stops to save time when leaving the station. The shock of the engine hitting the stops, even if not severe, is sufficient to upset many of the passengers on the footboard, especially on suburban trains. This dangerous practice is an indirect consequence of the safety measure which requires drivers to reduce the speed of their trains (3.72 to 1.86 miles an hour according to the Company) as they approach dead-end platforms. It must not be concluded therefrom that these

regulations should be rescinded ; quite the contrary : the shock at high speed would be very much more serious.

The most sensible instruction would be to require the speed to be reduced to 18.64 miles at about 1 100 yards from the stops, which is about the distance at which the points leading into important stations are situated. If this were so and the continuous brake failed for any reason (recent accident at the Gare de l'Est, Paris) the train could still be stopped by the reversing gear and the hand brakes on the tender and brake vans. It would also be as well if the speed had to be reduced to 3.72 miles at 110 yards from the stops to ensure that the wheels of the stock were not skidding, as the rails on such dead ends are wet and greasy owing to the engines which stand there. With the same object in view the control has issued regulations requiring the rails in terminal stations to be sanded by hand or by the engines.

Collisions.

Collisions or accidents, where one train runs into the side of another, take place when two trains on different lines meet usually at junctions either on running roads or at stations. It is unusual for them to occur at crossings (turntable roads and traversers). Usually the accidents occur in one of two ways :

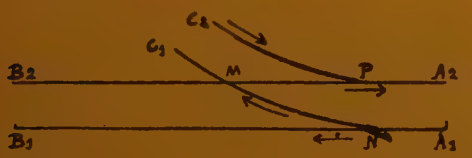


Fig. 1.

If A1 and A2 are the main lines (fig. 1) and B1, B2, C1 and C2 the branches from it, side on collisions can only occur at one point M where B2 and C1 cross and P the crossing of B2 and C2, but not at point N the crossing of B1 and C1 as the trains travel from A1 towards B1 and C1. The first type can be entirely prevented by means of the arrangement known as a « flying junction » which abolishes the « scissor » crossing, and consists in carrying one of the lines above the other. Two trains can then pass point M simultaneously without danger. To get this result the line C1 is taken from the opposite side to C2 with reference to B1 and B2 instead of from the same side and is carried over both B1 and B2 on a bridge or by tunnel, depending on the site.

This arrangement has been applied for the last twenty years to most junctions on lines with heavy traffic, and would have been more widely adopted still had it not been for the serious cost involved; the earth work and constructional work involved is usually very heavy. In addition to the advantage this arrangement has from the point of view of safety should the driver fail to act on the signals protecting the junction, it also enables a train for B2 and another for C1 to pass point M at the same time, which avoids many stops on B2 or on C1 and enables increased traffic to be handled.

The second type is not so easily prevented. It is of course out of the question not to join B2 and C2 at some point or other. In this case the signals and interlocking must be relied upon just as in the first type if a flying junction has not been provided.

Interlocking.

Interlocking consists in its essential feature in providing for the difference in position of signals and switches which should exist in an area controlled by one or two signal boxes. For example, at a junction it should be impossible to open the signals 2 and 4, one for line B2 and the other C2 (fig. 2) at the same time in order to prevent two trains meeting at point P. If one of the signals is off the other should be on, and vice versa. These signals should be interlocked with the lever of points No. 2 so

that all trains finding the signal off also find the points properly set.

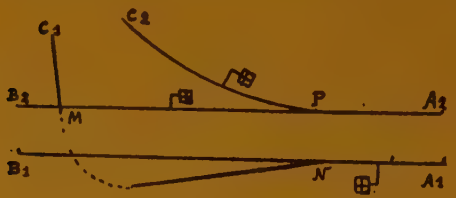


Fig. 2.

The interlocking can be done in several ways, that is, either mechanically by locking, or electrically by means of relays and electro-magnets or by electro-mechanical means. The first is the strongest and most reliable but takes up most room. We will not go into the details of interlocking as it would require an article to itself. We would like to note that these appliances should only be given a limited amount of confidence, as in the case of the block system and for the self-same reasons.

For one thing the pointsman can almost always find some means of getting round them after a few months' daily use, and for another the signals may not answer the movement of the lever operating them, in spite of all the care taken to meet failure of parts, and the use of appliances to meet such failures (accidents at Saint-Jory, Midi, 4 September 1919, and Châtelaudren, French State, 29 October 1922).

The only system in which one can have more or less complete confidence is where signal boxes are « power operated » in which the pointsman is only indirectly concerned with the working of the signals and points, and has nothing at all to do with the interlocking. These signal boxes can only be used to a limited extent in spite of the saving of staff effected, owing to their extremely high first cost and the special supervision they entail. Everything that has been said already about the observation of signals and the carrying out of the orders they convey applies to signals controlling junctions with even greater force than in the case of the block system signals. In most cases the distance from the distant signal to the point protected is only 110 yards or so in the case of a junction, whereas it may easily be 1 100 yards or more in the case of the block system. It is only very exceptionally that a train is stopped at the beginning of a block section; it is almost always at the end of the section near the semaphore at danger that trains stop, except when through an accident they have to stop in the section.

Consequences of accidents.

Having considered the principal causes of different kinds of accidents, it will be interesting to examine their common features as these determine the gravity of the accident, whereas the individual cause only explains why the accident occurred. It is more important to avoid the serious consequences of accidents than the accidents themselves, as the accidents only attract attention when people are hurt or killed.

The essential feature common to all accidents is that most of the damage done is due to the extreme violence of the stop the train makes so that it is in fact an inertia effect; this is undoubtedly so in the case of derailment or when one train runs into another. It is also so in the case of the train run into if we suppose, for argument, that the train colliding be standing and the train run into moving at equal speed and in opposite direction. In all case there is a bunching up of the train at one end. In the case of a train run into from the side, if the vehicle run into receives the shock in a direction other than parallel to that of the line, all the carriages following bunch up on it, as in the previous case, just as do those of the colliding train.

So that the consequences of an acci-

dent should be as little serious as possible, it is necessary that the carriages should offer a high resistance to shocks in the direction of their length, that the resistance be the same for all vehicles, so that there shall be no case of odd vehicles being broken up whilst the others remain intact. The strength and rigidity of carriages is therefore of prime importance for the safety of passengers, and, for this reason, the principal Companies have during the last twenty years provided for their express trains carriages with metal framing throughout, which offer high resistance to longitudinal blows. The reduction in the number of victims of railway accidents since 1921 has been due, to a large extent, to this measure.

Little damage was done in the recent derailments at Longueville (French Eastern and Pont-du-Clain (Paris-Orleans) in spite of the high speed (over 56 miles) of the trains : on the other hand there were many victims in the derailment at Saint-Antoine du Rocher (Paris-Orleans) in which the train was largely made up of lightly built stock although the speed was only about the same as in the above accidents.

The metal framed stock (bogie carriages of the principal Companies) has other additional advantages : they are heavier (about 40 t., instead of 20 t. in the case of the stock replaced) and they are connected by vestibules. These two things have made telescoping, which was responsible for many casualties owing to the weakness of the roofs much rarer than formerly. The vestibules also increase the resistance the train offers to being cut through when run into from the side.

It is evident that financial reasons will not allow all fast trains to be composed of bogie stock alone. Passenger trains should, it is to be hoped, be of uniform types of stock at least. It has been noticed frequently that after an accident lightly built stock between heavier vehicles has been broken into bits as though it had been passed through a press, whereas the heavy stock was only lightly damaged. When the train is made up of the same type of stock the damage is divided amongst a large number of carriages, and is thereby much less serious.

For this reason it is necessary that the brake vans on trains composed of heavy stock should also be equally strongly built in spite of the extra dead weight involved. It would be an advantage if the bodies of vans were shorter to make up for the absence of partitions. These vehicles bear the brunt of almost all accidents as the train bunches up at the head or in the rear, and the brake is crushed against the enormous mass of the locomotive and tender, whether it be that of the train itself against the front brake or the colliding train against the rear brake. Until recently fairly light vehicles only were used as brakes, and the guards were nearly always amongst those killed — in fact more often than the enginemen, who were better protected. The use of heavy brakes reduces the likelihood of derailments by reducing the amount of nosing to which light vehicles placed in the rear of fast trains are liable.

The increase of dead weight could be made use of either by using part of the vehicle to carry passengers or by suppressing the rear brake, the rear guard travelling in the last carriage and the luggage being loaded in the front van.

Influence of speed.

Everything we have said so far as to what can be done to reduce the seriousness of accidents and their number, presupposes that the conditions under which trains are to run have been settled. We have said nothing about this. It is not that these conditions have only a secondary influence on the frequency and gravity of accidents, quite the contrary, but any alteration in the running

conditions is very difficult to realise in practice as it affects the train service and thereby the public, which to-day is very critical.

We have also shewn that the damage done was almost entirely due to inertia, the importance of which varies with the square of the speed. The possibility of accidents happening also increases with the speed. Although some causes of accident do not appear to be affected by the speed most of them such as derailments through split points and broken points, inattention to signals, errors in handling the brake, etc. are to a great extent. The influence of speed is therefore very great, and this is why all serious accidents occur to express and fast trains. The best way therefore to reduce the frequency and gravity of accidents is to limit the speed as much as possible. There are, however, two factors that prevent this : the demand of the public to travel safely and fast; the need for economical operation. A priori this seems contradictory as the cost of traction increases rapidly with the speed. In practice to run at the lowest speed consistent with losing as little time as possible, necessitates the speed being as constant as possible. The speed is greatly influenced by the profile of the line : the ideal from the point of view of economy is to let the trains ascend gradients as slowly as possible and run down them as fast as they can, so that the question of economy is against a lowering of speed restrictions. So far as public demands are concerned, the Companies make a mistake in paying too much attention to them : the public really wants not so much speed as punctuality.

A moderate reduction in speed, say from 56 to 50 miles, for example, diminishes the danger to passengers in the ratio of 3 to 2. Undoubtedly if the Companies reduced the speed of their fast trains in such a proportion the risks of accident with the prejudice and loss they cause would be sensibly reduced. The running costs also would be lowered as in the case of expresses they are considered to be proportional to the square of the speed. The public would hardly notice the reduction of speed and would soon forget it if in return the service was more reliable.

It must also be said that the speed could often be reduced without taking a longer overall time for the journey by removing unnecessary speed restrictions and stops : water colums could be replaced by troughs from which water could be picked up when running (Ramsbottom scoops) and by using large capacity tenders. The number of times engines are changed could be reduced by running each one longer distances, which could be done without overworking the enginemen if good fuel were used.

Whatever the maximum speeds may be it is essential to see that they are not exceeded. The best method is to allow a little more margin in the timing of the trains than they have at present so that the enginemen may pick up more of the time lost, and above all to insist on the drivers obeying the speed limits in force. The railway drivers are really a very fine body of men and an example to most other groups. In spite of all the improvements introduced for their benefit in recent years, their occupation is still one of the most trying in existence owing to the particular conditions under which it is carried out : night work, Sunday work, meals at all hours, frequent absences from home, no definite programme of duty, and much unavoidable dirt. It is a trade that is physically trying, demands strict sobriety, and prematurely uses up the strongest men. It taxes the men mentally as it demands continuous attention, quick decisions, and a sense of superiority to enable the driver to make fireman obey his orders.

In spite of all difficulties, our drivers give proof of a fine professional conscience and a strong sense of discipline,

which are particularly meritorious in this age. It must be admitted that undue advantage has sometimes been taken of these now rare qualities, and that unreasonable demands have often been made upon them.

In the public interest as well as in that of the drivers, this craving for speed which was given way to too much, and especially just before the last war, should not be gratified but the drivers given more margin in handling their trains. The deliberations of the Commissions considering the steps to be taken to ensure greater safety would appear to be moving in this direction.

Finally, it is necessary to run at slower speeds if we wish to run more regularly, more safely, and more economically. So far as finance will allow, the track and rolling stock should be improved, and the confidence of the staff must be restored by providing him with such equipment as will assist him in carrying out his duties.

[385. (09 3 (.42)]

SOME RAILWAY NOTES OLD AND NEW, (1)

By Sir JOHN A. F. ASPINALL, D. Eng.

Figs. 1 to 21, pp. 738 to 761.

(*The Proceedings of the Institution of Mechanical Engineers.*)

Our Past-President, Mr. Patchell, when he asked me to deliver the Thomas Hawksley Lecture, expressed a hope that I would deal with some matters concerning railways, particularly as it was the Railway Centenary Year and our first President, George Stephenson, who was the great creator of British railways, was being thought of in all parts of the country. I felt considerable difficulty in following this course because of the immense amount of literature which has been got together during the past few months dealing with this subject of the early days of railways, and it seemed to be impossible to say anything new upon the matter. This difficulty has, to my mind, been considerably increased by the fact that a most exhaustive and complete record of locomotive history has been produced during the past few months in the pages of *The Engineer*, so that there is but little to tell which is not already known to the public.

In thinking the matter over, however, and looking back over the long series of years during which I have been connected with railways, I thought there were still a certain number of things which had not hitherto been published, and other things which may have been published but which have been forgotten, which might be of some interest to our members, and therefore I hope I may be forgiven if I have put forward information which is not really new.

It is interesting to note how early our First President became connected with railways, and an instance of this is found in the fact that a tablet has been erected in the front room upstairs at the *George and Dragon* inn at Yarm-on-Tees,

(1) Paper read before the Institution of Mechanical Engineers on 6 November 1925.

North Yorkshire, to commemorate the first railway meeting that was ever held in England, in 1820. George Stephenson was present at this meeting, and it was then decided to apply to Parliament for powers.

Again, in addition to the Stockton and Darlington line, George Stephenson laid out the Canterbury and Whitstable line in 1825, afterwards constructed by his son Robert. The difficulties which were thrown in his way were stupendous, but he overcame them all by his steadfast purpose.

As a nation we have some curious ways of dealing with new proposals, and as an instance it will be recollected by some of our senior members how, when it was proposed to build the Suez Canal, the main opposition came from England, the whole project being ridiculed. Again, when it was proposed to create the great dam on the Nile at Assuan, most strenuous efforts were made by our archæologists and others to prevent this being built for fear that it might depreciate the ruins of Philæ. This kind of difficulty had also been raised when railways were first started, and it is very curious to read some of the objections that were given at the time.

For instance, a Mr. Donald Currie raised strong objections to railways in 1837 because « veins of water will be cut, springs dried up, and sloping fields so deprived of water that they will become sterile and unfit for pasturage and agriculture. Whole estates are cut asunder and disfigured by deep cuttings ». He therefore proposed what he called a safety railway, by constructing it of « timber or other materials raised at least ten feet above the ground », removing every obstruction to agricultural operations. Time and knowledge have, however, changed all that.

Prosser's angular wheels. — A great many odd proposals were made in the early days of railways with regard to the rolling-stock which should be used upon them, but I think the most curious was that of Mr. William Prosser, who proposed that there should be no flanges on the carrying wheels of locomotives or other rolling-stock, and that the vehicles should be kept upon the line by certain angular guide-wheels pressing on the top and sides of the rail. This system was said by the Author, who patented it in 1844, to have been first adopted on the Guildford & Woking Railway, and that the locomotive had travelled during a period of two months about 3 000 miles without requiring the slightest repair. An illustration of his proposals is shown in figure 1.

Plateway. — It is recorded in a Paper by Clement E. Stretton, entitled « The History of the Preston and Walton Summit Plate-way », that the Lancashire & Yorkshire Railway Company ultimately came into possession of parts of the « Outram-way » of the Preston and Walton Summit line which had been made by the Lancaster Canal directors under their Act of Parliament of 1792. Originally this tramway was worked by what was then called a « fire-engine », that is, a steam-engine with boiler for pulling the wagons up and down the incline of 1 in 6 by means of a continuous chain. The new tramway was about five miles in length, and had up and down lines of plates. The plates were of cast-iron, each one yard long, and had an upright ledge or flange upon the inner side in order to keep the flat wheels upon the line. Each end of each plate was held down by two iron bolts or spikes, and rested upon stone blocks instead of upon sleepers. Each block was 2 feet long, 1 foot wide, and 10 inches thick, and had two holes drilled into it in order to receive wooden plugs, into which the spikes were driven. This line of tramway gave birth to the expression « platelayer », as the men who fixed the plates to the stone blocks were called « plate-

layers », and that name has continued to exist although plates have been superseded by rails.

I will now give you some illustrations of the carriages used on early railways.

Horse-drawn coach on a railway. — Figure 2 shows a railway as used in the early days in South Wales, when the carriages were hauled by horses. It will be observed that the wheels and the springs were of a design which continued to be used in a modified form for a great many years after steam railways came into existence.

Carriages. — On the Manchester and Leeds Railway, which was the parent line of the Lancashire and Yorkshire Railway, it is recorded that :

Carriages consist of first class weighing 8 100 lb.; second class, of three compartments, open at the sides, with wooden sliding shutters instead of glass sashes, weight 6 150 lb.; third class or Stanhopes, 17 feet long, 8 ft. 8 in. wide — four entrances, the whole divided into four compartments by a wooden bar down the middle, and another across intersecting the first at right angles. Weight of this contrivance 5 050 lb., and the number of passengers it will contain depends upon the bulk of the stanhopers.

An extract from the minutes of the meeting of the directors of the Manchester and Leeds Railway on 23 July 1838, gives a vivid impression of the deliberation with which it was determined to prevent the accommodation in a third-class carriage being too good. The minute is worded as follows :

« Resolved 1st :

That there shall be three classes of carriages provided :

First class. — 6 inside, complete with everything which can conduce to comfort.

Second class. — To carry 24 passengers; division chair high; windows in doors but none in the panels, and no cushions.

Third class. — Open boxes; no roofs nor buffer springs. »

There has been a surprising change in the standard of comfort with regard to railway carriage stock.

The screw coupling which connects modern railway carriages in this country is said to have been invented by Mr. Nathaniel Worsdell, and was first made by him at the Crown Street works of the Liverpool and Manchester Railway.

Most people are familiar with the old illustrations of the four-wheeled carriages which were first used, but they may not have noticed how low the roofs of these carriages were made, with a railing round the top which was put there to enable baggage to be loaded on top, then sheeted over with a waterproof sheet, and then strapped down with great leather straps running from side to side. When one remembers that the tunnels and bridges of to-day are no higher than they were then, it will be appreciated how necessary it was to keep the roof of the carriage down to allow for the baggage passing safely.

Figure 3 shows the form of railway carriage which was used on the Liverpool and Manchester Railway. It will be observed that the body of the vehicle is made to represent three coach bodies of the old road form, and the shape of the panels was followed on other railways for some years. Figure 4 shows the opening of the Albany and Schenectady Railroad in America in 1831, where it will be noticed that the actual old coach bodies were taken off their road wheels and put on to trucks made for the railway. Here again the shape of the panels followed the British practice.

Then we have Frith's picture of 1850, figure 5, which shows a train going out

Fig. 1. — Prosser's angular wheels, 1844.

Fig. 2. — Early railway travel in South Wales.

Fig. 3. — Coach used on Liverpool & Manchester Railway.

Fig. 4. — The opening of the Albany & Schenectady Railroad with the *De Witt Clinton* locomotive, 9 August 1831.

of Paddington Station (1). Following the ordinary practice of the day, the roofs of the carriages were made extremely low, and the passengers' baggage was piled on the top as previously mentioned and then carefully sheeted over to protect it from the weather. In this figure the porters can be seen in the act of dealing with the baggage. It is interesting to look at this picture, as on the extreme left you will see one of Daniel Gooch's locomotives standing beyond the train.

Figure 6 shows a carriage of the Bodmin & Wadebridge Railway built about 1834, which can be seen any day on its pedestal on the concourse of Waterloo Station. This is a particularly interesting vehicle, as it shows how the old methods were continued, with the further interest that the carriage is standing on the original rails, chairs, and stone sleepers, which give a perfect record of the methods of the past. The second-class carriage on the same railway was a mere square box.

Very much later on, when I went to the Great Southern & Western Railway in 1875, I found that they still possessed a number of carriages built in this way, probably made in the early « Forties », arranged for the carriage of baggage on the top, though this practice had been long discontinued. One of these vehicles is shown in figure 7. This continuation of the old pattern of coach body is only another illustration of how long it takes to leave behind old practices when there is no longer any reason for their existence, except that their builders had got into a rut.

The late Lord Leverhulme said that « you ought to endeavour to get out of ruts, as a rut and a grave are very much like one another, except that the rut is longer. They have this difference, however, that you can get out of the rut, but you cannot get out of the grave ». This tendency in adhering to old patterns was well illustrated in modern times when first motor-cars came in, and it was impossible for some time to get the coach-builders to depart from those forms of body which had been in use with horse-drawn carriages.

Figure 8 shows some of the railway carriages which are still used running round Paris, which are double-decked, seats and a roof being provided above the ordinary ones so as to admit of a double set of passengers. These carriages have been in existence for a good many years, and they are one of the best illustrations I know of the very large loading gauge as regards height which is in existence on the particular railway on which these carriages are used. There is no railway in England which could permit these carriages to run through its tunnels or under its bridges.

The six-wheeled carriage was looked upon as a great advance upon the four-wheeled vehicle, though it is strange to see some four-wheeled vehicles yet in use. This was followed by the bogie vehicle, though for a short period on the London & North-Western Railway they used a radial axle-box at each end of an eight-wheeled carriage, which was intended as an alternative to the bogie. It was by no means a success, as the ends of the coaches swung over considerably at the curves and the carriages were uncomfortable to ride in.

Lighting of carriages. — The lighting of railway carriages has undergone an immense improvement. Some of you, however, will recollect what it used to be like in the old days of the oil lamp, when but little attention had been paid to lighting efficiency, and in the third-class carriages one lamp was expected to serve for two compartments by the expedient of cutting a half-round hole in the partition between the two com-

(1) Illustration of this picture has been given in the number of November 1911, p. 1392, of the *Bulletin of the Railway Congress.*

Fig 6. — London & South Western Railway. Original coach and permanent way used on the Bodmin and Wadebridge branch from 1834 to 1886.

Fig. 7. — Coach, Great Southern Railway (Ireland), 1875.

Fig. 8. — French double-deck carriages.

partments and inserting the lamp in such a way as to shine both ways. These very inferior lamps were followed by much more efficient lamps burning mineral oil and giving a light which, though better, was very difficult to read by. On the French railways, however, they tackled this question very much earlier, and made some very good oil lamps fitted with a glass chimney, which gave a good light.

Then came the time when ordinary coal gas was stored on the tops of the Metropolitan Railway carriages in containers of the accordion type, the pressures being maintained by weights which tended to force the accordion downwards. This use of ordinary coal gas, however, led to a good many troubles, because of the tendency of the hydro-carbons to become deposited in the gas pipes and necessitate their being frequently cleaned out.

Later came the system of oil gas lighting, which was quite efficient, but did not give a brilliant light with ordinary burners. This again was much improved when the incandescent mantle came into use, and during the War, when there were difficulties about oil, it was found that a mixture of coal gas and of oil gas in combination with the incandescent mantle, gave an excellent light.

With regard to electric lighting that, of course, is familiar to everybody, but as each carriage has got its generator running underneath the coach, being driven from a pulley on the axle, each carriage becomes a travelling generating station, the power for which has to be supplied from the locomotive. It is much more expensive to install and to operate. The coal consumption which takes place in the fire-box of the locomotive to produce this current represents about 4 lb. of coal to the train-mile with a train of about ten carriages running at 40 miles an hour.

Heating of carriages. — Many will remember how for a number of years no attempt whatever was made to warm the carriages, but that later foot-warmers were introduced, which involved a great deal of handling and which were by no means very efficient, as they did not remain very hot for long and were not of much value on a long journey.

The modern method of steam heating involves more work by the locomotive boiler, and it is probable that lighting, which is mentioned above, and heating during the winter time, when taken together, mean from 10 to 15 % of coal added to the ordinary locomotive expenditure for fuel on passenger trains in the winter during the hours of user.

Axles and tyres. — In the early days the methods of manufacture of axles and tyres had not reached the perfection of to-day, and it was a long time before steel was used for either tyres or axles.

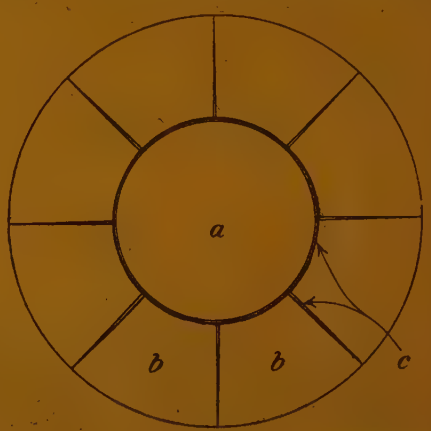


Fig. 9. — Cross section of a wagon axle journal made up of numerous pieces intended to be welded together.

a = Soft iron core.
b = Segments of harder iron surrounding soft core.
c = Interstices between segments and core due to bad welding.

Iron axles were made by a number of firms in this country, and an endeavour

was made by one firm to construct the journal of wagon axles in such a way as to give a hard wearing surface while the centre portion of the journal was made of softer iron.

No doubt when these things were first made they would be turned out with great perfection and all the surfaces welded together with great care, but as time went on it was found out that many of them were of very defective character, and the illustration, figure 9, shows what was the cause of the failure. It was quite easy to put the blade of a penknife in between these surfaces, and, as the journal wore, the exterior surfaces which had been held together by better welding no longer served to make a reliable journal. I have more than once, between 1875 and 1886, brought a striker out of the smithy to give one of these journals on a pair of wheels standing in the shop two or three sharp blows, when it would break off like a carrot. Needless to say, this kind of thing has long ago disappeared.

The same idea of getting a hard surface must, however, have been in Mr. John Ramsbottom's mind when he had all the tender axles at Crewe thoroughly case-hardened.

The best indication that can be given of the improvement that has taken place in axles is the fact that failures have decreased systematically during a long course of years, the following statement showing the number of broken tyres and axles in Great Britain since 1875 :

Statement showing the number of broken tyres and axles in Great Britain since 1875.

Year.	Broken tyres. Number.	Year.	Broken axles. Number.
1875	554	1875	461
1880	1 230	1880	494
1885	918	1885	364
1890	577	1890	249
1895	454	1895	182
1900	233	1900	163
1905	159	1905	127
1910	98	1910	101
1915	78	1915	90
1920	54	1920	107

Detailed returns.

Year.	Axles.	Year.	Tyres.	—
1922	Engine . . . . 14 Tender . . . . 2 Coach . . . . . 3 Wagon . . . . 36 Total. . . 55	1922	Engine . . . . 53 Tender . . . . 13 Coach . . . . . 14 Wagon . . . . 9 Total. . . 89	Crank or driving . . . . . 35 Leading or trailing 18
1923	Engine . . . . 18 Tender . . . . 1 Coach . . . . . 5 Wagon . . . . 46 Total. . . 70	1923	Engine . . . . 46 Tender . . . . 17 Coach . . . . . 10 Wagon . . . . 11 Total. . 84	Crank or driving . . . . . 33 Leading or trailing 13

It will be observed that in cases of broken axles the number has fallen from 494 in 1880 to 84 in 1923, while with regard to broken tyres the numbers have fallen from 1230 in 1880 to 70 in 1923. The large number of tyres in the earlier years which are shown to be broken was due very largely to the fact that a great many old iron wagon tyres remained in existence, and these used to fail circumferentially due to bad welding.

When, in later years, the Government returns were so subdivised as to show the numbers of engine, tender, coach, and wagon axles or tyres separately, it will be observed that the number of broken crank-axles has fallen to 33 in 1923. Having regard to the fact that there are, roughly, 24 000 locomotives in this country, this is quite a remarkable record.

Battle of gauges. — The battle of the gauges in this country is still within the memory of many people, and it is not so many years since the Great Western altered from their 7 foot gauge to the ordinary 4 ft. 8 1/2 in., but it is not so generally known that in America they had a great variety of gauges. I remember that when over there in 1872 I was greatly struck by seeing a number of their freight-cars labelled « broad tread » and « narrow tread », and when I came to inquire as to the reason of this, it appeared that there was a variation of gauge, some of the railroads being 4 ft. 10 in., others 4 ft. 9 1/2 in., and others 4 ft. 8 1/2 in. The intention was that these freight cars or other vehicles should run upon any of these tracks, and for that purpose, while the flanges of the tyres were sufficiently near to one another to permit of their running safely on a 4-ft. 8 1/2 in. gauge, the tread of the tyre was wide enough to prevent it dropping in between the rails on a wide track of 4 ft. 10 in. I am indebted to Mr. J. T. Wallis, chief of motive power of the Pennsylvania Railroad, for the exact facts as to these differences of track-gauge, and these facts will be found set out in an Appendix (page 764).

The Ministry of Transport, in the early part of this year, issued both their regulations with regard to new railways, and their recommendations with regard to the changes on old railways, and these documents are of considerable interest to engineers. The result of following these regulations will be to make considerable improvements both in the structure gauge of the railways and in the strength of bridges. The immense variety of the structure gauges on the railways in this country has prevented the construction of larger rolling stock, and we are not in the same fortunate position as the railways on the Continent, who can make their vehicles up to what is known as the « Berne » gauge.

In order to illustrate (*a*) what is known as the structure gauge, and (*b*) what is known as the loading gauge, figure 10 is shown, which gives all the leading dimensions with other particulars in the form of notes. This figure is a reduced copy of the new Government Regulations. Allowances are made so that ample clearance will be assured for any overhead electric equipment which may be placed in tunnels or under bridges in the future, but the whole diagram becomes worthy of study as showing the great difficulty of finding space for the attachment of anything more to the rolling stock than is found in practice today.

As to the question of existing gauges, figure 11 is shown, which gives the old Lancashire and Yorkshire load gauge as being 9 feet wide, while that of the Continental railways known as the « Berne » gauge is 10 ft. 2 in. wide. On the right-hand side will be found the top contact rail in the position in which it is used on the electric railways in the North of England, and next to it the top contact rail in the position in which it is used on the electric railways in and about

Clearances with overhead electrical equipment. New and existing lines.

Between any part of bow gear and structure = 3" absolute minimum.

a = clearance between load gauge and underside of conductor
= 10" desirable standard
= 4" absolute minimum.

b = clearance between structure and upper side of live equipment
= 6" desirable standard.
= 4" absolute minimum.

X = depth of live wire construction and flexibility.

Clearance between load gauge and structure.

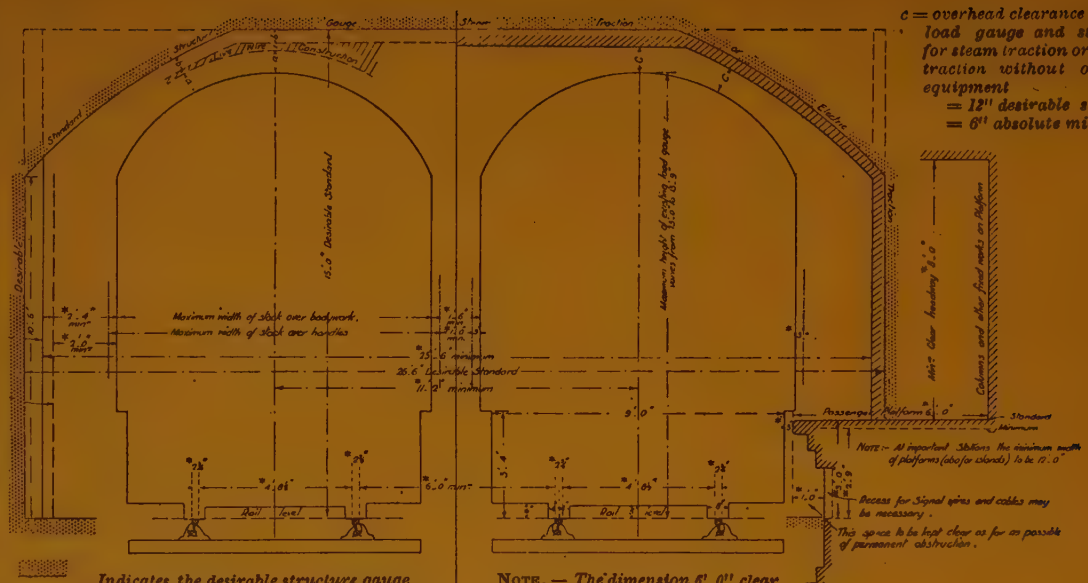
New lines, with possibility in future of electric traction = 10" minimum.

Minimum face of structure or of stanchions carrying overhead electrical equipment.

Face of signal and lamp posts ladders, water columns, etc.

In cases of difficulty, where signal posts, etc., are placed between tracks spaced at 9'.0" interval, a minimum clearance from bodywork of 18" is permissible.

c = overhead clearance between load gauge and structure for steam traction or electric traction without overhead equipment
= 12" desirable standard
= 6" absolute minimum.


Gauge
Structure
Standard
Double Standard
Maximum height of Loading Gauge above Rail Level
Maximum width of stock over bodywork.
Maximum width of stock over handles
25'.6" minimum
26.6" Desirable Standard
11'.2" minimum
9'.0"
Platform 5'.0"
Standard Minimum
Columns and other fixed posts on Platform
Note:- At important Stations the minimum width of platforms (also for islands) to be 12'.0"
Recess for Signal wires and cables may be necessary.
This space to be kept clear as far as possible of permanent obstruction.
Rail Level
6'.0" min.

Indicates the desirable structure gauge which is recommended for adoption in the case of new and reconstructed lines.

This gauge does not shew permissible infringements in respect of conductor rails, guard and check rails, water troughs, train stops, and structures in the 6 ft. way, above the level of the running rails.

NOTE. — *The dimension 6'.0" clear between tracks has to be increased to 10' 0" (or in cases of special difficulty to 9'.0") when additional single running lines or pairs of double lines are laid alongside existing main lines.*

Fig. 10.

Reproduced about 1/3rd original size.

CLEARANCES

CONSTRUCTION OR RECONSTRUCTION, ALTERATIONS OR ADDITIONS.

Diagram illustrating lateral and overhead clearances on straight double track in accordance with the requirements 1925.

NOTES. — *(1) It will be necessary to make allowance for curvature, superelevation, and length and contour of rolling stock in order to maintain the clearances indicated;*

*(2) The dimensions marked * are those referred to in, or are derived from the requirements.*

(3) The diagram does not apply to tube or sub-surface lines.

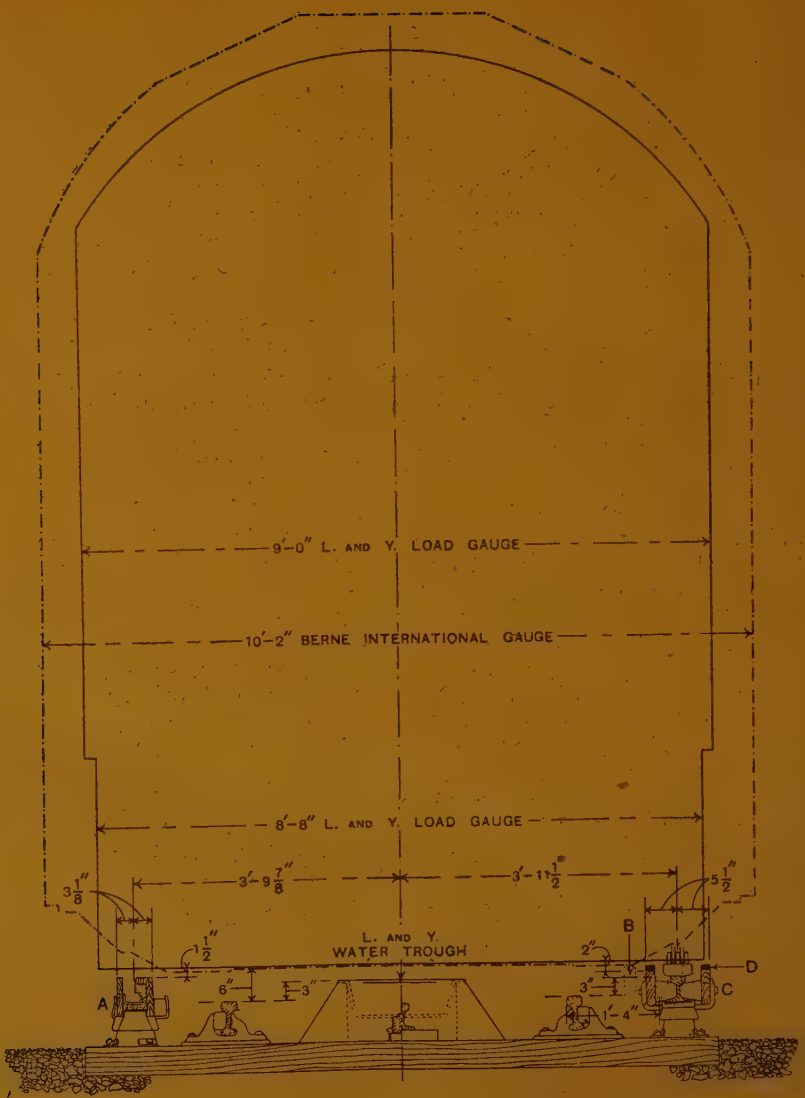


Fig. 11. — The « Berne » international gauge compared with the Lancashire & Yorkshire Railway load gauge.

A = M. & B. . . . . Third rail and guarding.
B = L. & S. W. . . — — (Dotted on right.)
C = L. & S. . . . . — — »
D = Railway clearing house, position of guarding.

London, while on the left-hand side will be seen the side contact rail which is in use on the old Lancashire & Yorkshire Railway for their 1 200-volt electric lines running out of Manchester.

Two forms of fourth rail are shown in the centre of the track which indicate from their position that a water trough, which is also shown, cannot be laid down on the same length of railway. This has an important bearing on the question of the suspension of triggers for the operation of automatic signalling or methods of train stopping.

A very apt illustration of the difficulties created by small construction gauges and weak bridges at the present time is shown by the fact that when the Great Western Railway and the London and North Eastern Railway recently exchanged locomotives for trial upon their respective lines, and the North Eastern locomotive had to go from King's Cross to Paddington, a distance of about 3 miles as the crow flies, it was necessary to send it as far north as Sheffield to get back to Paddington, a distance of about 300 miles. On the map it would look as if it could have gone by certain railways with a very much less mileage, but in one case the gauge was too small to allow it to pass through the tunnels; in another case the bridges would not carry the engine, and in the third case the bridges again prevented its being safe to send the engine by that route.

Signalling. — To appreciate the immense advance that has been made with regard to signalling and train stopping which has enabled such a state of modern railway efficiency to be produced, you have only to read an old railway rule book to see that in 1846, on one of the railways where signals did not exist, and they controlled their trains by time and distance, it said :

All engines travelling in the same direction shall keep six hundred yards at least apart from each other, that is to say — the engine which follows shall not approach within six hundred yards of the engine which goes before; and in coming down any of the inclined planes the following engine shall not come within nine hundred yards of the train which precedes it.

The changes which have taken place with regard to signalling have been very great. Step by step improvements have been made, not only for the sake of saving time, but mainly for ensuring absolute safety if the appliances are properly used. Signalling not only includes the visual signals by which the driver is guided, but those very numerous appliances of an electrical character connected with the progress of trains.

The description of these would require a volume in itself, but I have seen within my own time the change from the simple handworked semaphore to the careful interlocking of all points and signals which control the proper sequence of movement, and later either the electric pneumatic, or the all-electric equipment in the modern signal-box where the hard work of the signalman has disappeared, and he effects the movement of a set of points or a signal by means of a small lever which requires no physical exertion.

The most modern change has produced signalling by lights, both by night and day. The block instruments, perfect telephonic communication between signal-boxes, and the existence of track circuiting in those places where it is found to be necessary, electrical signal repeaters, and, in some cases, arrangements for lock and block, have all tended to relieve the anxieties of the signalman, and thus enabled him to deal with a larger number of passing trains without undue strain. All these appliances have added a great deal to the cost of railways, but they have come about mainly to ensure our modern requirement of « safety first ».

It will be recognized that every effort

to increase the capacity of a railway and to pass a larger number of trains per hour over any one set of rails, requires a close investigation of the methods by which minutes and even seconds may be saved and time margins reduced, coupled with a demand for those safeguards which will enable the work to be done with safety. It is perfectly true to say that intense density of traffic has been the creator of modern safety appliances.

In the early « Seventies », long before the block system of to-day had been brought to its state of perfection, there was not that keen appreciation of risks which must be avoided. When I was working as a fireman running between Crewe and London, it used to be the practice, when a train arrived at Crewe which was a little heavier than the limit allowed, for the locomotives of the Ramsbottom « Lady of the Lake » class, which then hauled all the expresses, to attach another 7 ft. 6 in. wheeled engine of the same class in front, which went as far as the top of the incline at Tring.

When some little distance away from the signal-box at Tring, the fireman on the front engine climbed to the back of the tender and unhooked the coupling between the first and the second engine. The driver then gave five whistles and, while the driver of the train engine slacked a little, the driver of the first engine ran ahead as fast as he could past a pair of points leading to a siding and then backed rapidly into that siding, the train following without stopping and passing these points a few minutes later. This practice would be quite sufficient to make the hair of a modern railwayman stand on end.

It must be recollected that on these trains there were no continuous brakes such as we have to-day, and therefore the stopping power depended entirely upon the hand-brakes on the tender and on the guard's van.

I did not think that such a thing happened elsewhere, but shortly afterwards I went to America to look at some of the American roads, and travelled on a train from Altoona on through the Horseshoe curve, and then through a tunnel. I was on the footplate of the first engine, and I was astounded when we got out of the tunnel to find that the first engine was running sharply off to the right, having been turned on to a siding through a set of facing points, and I saw the train a second or two later passing off to the left on the main line. The block system has altered all this in this country, and has created a perfection of check which is responsible in a very large measure for the present safety on railways.

To-day, of course, we have in many cases automatic signalling, and upon our underground systems, where automatic signalling is very much more easy to deal with than on main lines with complicated sidings, we have the arrangement whereby the train is brought to a stand by an obstruction raised on the permanent way striking the trigger on the motor vehicle in front, which at once applies the brake in the event of the driver passing the danger point. One of the first applications of this kind of thing which is known to the Author was that produced by M. Lartigue and fitted on the Northern Railway of France in the early « Seventies », where a copper brush was suspended under the footplate of the locomotive, which came in contact with what they called a *crocodile*, which was a piece of timber covered with a brass plate; and should the signal be at danger, an electric current was conveyed through this copper brush to an arrangement on the foot-plate, which put the brake on.

Six brief descriptive Papers on « Signalling on railway trains in motion » were read by French engineers at our Paris meeting in 1914 (1). Also five brief Papers by English engineers on

(1) *The Proceedings of the Institution of Mechanical Engineers*, p. 463.

« Audible and other cab signals on British railways » at our London meeting in the same year (1).

Continuous brakes. — Continuous brakes were in use on the Lancashire & Yorkshire Railway in 1853, the form of brake being that known as the « Fay and Newall » brake, which was applied by the guard throughout the train by means of a shaft that went underneath all the carriages and had universal joints with a telescopic arrangement between the carriages to allow not only of the rise and fall of the vehicles, but of the compression of the buffers. These brakes remained in use for many years, and of their kind were very efficient.

Then came the time when the Westinghouse brake was first introduced into this country in its non-automatic form, to be followed not long afterwards by Smith's vacuum brake, which was operated by means of an accordion-like rubber cylinder, this form of brake being later much improved by the use of what was known as the « Hardy » cylinder, later by the « Clayton » cylinder.

The London & North Western Railway, desirous of avoiding the use of the continuous air-pressure brake, adopted a form of chain brake with the chain running throughout the train, which was applied by the guard and was worked by a drum on the axle. It was not an experiment which lasted long, as it was extremely harsh in its application and on more than one occasion led to breakaways.

Later on, pressure from the Board of Trade resulted in modifications of brakes, making them automatic in the event of an accidental severance of a train. The first so altered was the Westinghouse brake. This was followed by the vacuum brake being made automatic, with the result that in this country all passenger vehicles are fitted with either the vacuum brake or the Westinghouse, and some goods vehicles also.

The number of goods vehicles fitted with continuous brakes is comparatively small, but it is to be hoped that this will be changed as rapidly as it is reasonably possible, because the tendency is to haul heavier goods trains; and they could be made even heavier than they have been, in any case at present, if all the vehicles were fitted with continuous brakes so as to give the power of stopping rapidly, whereas now the trains are almost wholly dependent upon the brake on the engine and in the guard's van. If this modernization took place, the length of goods trains in this country would only be limited by the strength of the three-link coupling between the wagons.

The introduction of continuous brakes led to careful investigation on the part of Captain (afterwards Sir Douglas) Galton and Mr. George Westinghouse of the results of skidding, and they showed quite clearly that :

> The resistance which results from the application of brakes without skidding is greater than that caused by skidded wheels. Just at the moment of skidding, the retarding force increases to an amount much beyond that which prevailed before the skidding took place; but immediately after the complete skidding has taken place, the retarding force falls down again to much below what it was before the skidding.

The result of this was that in some cases in the early days of continuous brakes, when the brake was improperly applied and the engine wheels skidded, the engine lurched forward at a higher rate of speed and broke the couplings between the engine and the train.

Those who are interested in this subject are referred to the Proceedings of this Institution, 13 June 1878, 24 October 1878, and 24 April 1879.

Sand drag. — The most effective train

(1) *The Proceedings of the Institution of Mechanical Engineers*, p. 843.

stop, however, for use in case of runaway trains that has ever been produced, is the sand drag. This was invented by an Austrian engineer named Herr C. Kopcke, of Dresden, but it was first applied in this country by the London & North Western Railway in the tunnel which runs from Edge Hill, Liverpool, down to their Waterloo Dock Goods Station, figure 12.

It consists of a second pair of rails laid in close to the main track, which rails are enclosed, as it were, in a wooden through, the sides of which stand up about 3 inches above the rails. The internal space is then filled in with either sand or fine gravel kept level with the top of the throughing. In the event of a runaway train the signalman can divert the vehicles from the running road into the sand drag. The retarding effect is instantaneous, and the whole of the runaway vehicles are rapidly but gently brought to a stand.

The action of the drag is such that it applies itself equally to each vehicle in the train, and if it be a goods train, the couplings of which are at full stretch when the train enters the sand drag, they remain at full stretch through the whole period of the journey through the drag, and there does not seem to be any tendency to buffer up. It has frequently been found with such drags as these that it is most difficult to move the train back again into its position on the main line, even down an incline, and a second locomotive has to be brought into use before it can be shifted.

Some curves which show clearly the rate of retardation in the Waterloo Tunnel experiments were given to me in 1902 by Mr. Footner, the London and North Western Railway engineer who first laid down these sand drags in this country, and these are reproduced in figure 13.

It will be found that there are slight discrepancies in the figures shown for the length of the wooden trough and the depth of the sand between figures 12 and 13, the former representing what was carried out for the permanent arrangement, and the latter what was done in the case of the first experiments.

A statement was recently made about a drag on another railway (the Great Western) where, upon an incline of 1 in 57, a drag 1 000 feet in length had been installed, a train under runaway conditions weighing 1 003 tons and running at 33 miles an hour was brought to a stand in thirty-two seconds. I had a number of these sand drags laid down on the Lancashire and Yorkshire Railway and the experience gained from them was wholly satisfactory, and they had the effect of saving many serious accidents on inclines.

Inspection of railways. — For a large number of years now all railway accidents have been inquired into by the Inspectors of either the Board of Trade or the Ministry of Transport, who have exercised constant vigilance in suggesting changes or improvements which would minimize any railway risks that may exist.

There have no doubt been differences of view as between the Government inspectors and those who control and operate the railways, but these have only had the effect of creating further study of the points in question, which study has resulted in the end in agreement as to what is really desirable. There is no doubt, however, that the railway companies have appreciated the absolutely impartial investigations which these inspecting officers have held into the various matters which have been submitted to them, and the public have to thank them for the patient care with which each case is gone into.

I do not propose to give many illustrations of locomotives for the reasons stated in the first part of this Lecture, but I think one illustration of an old American locomotive is of interest.

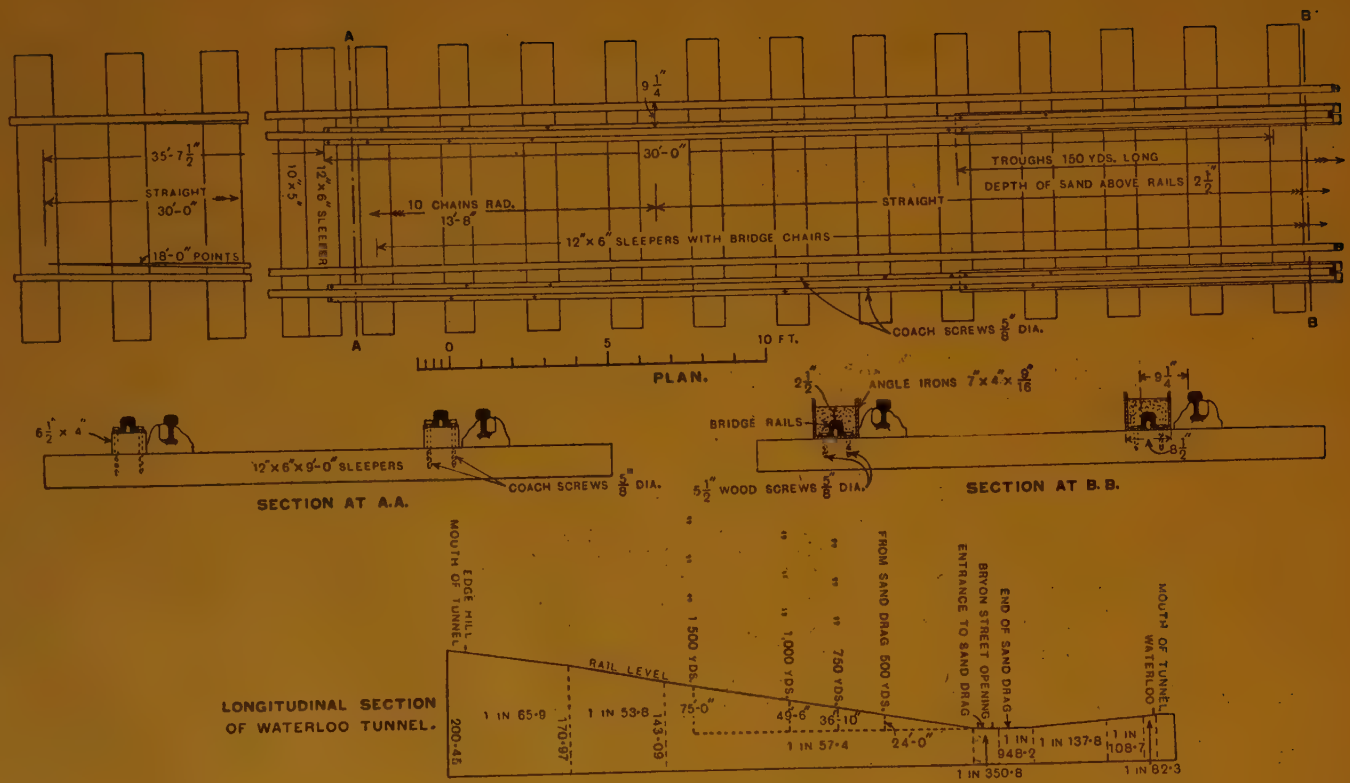


Fig. 12. — Details of catch siding leading to sand drag in Waterloo tunnel, Liverpool.

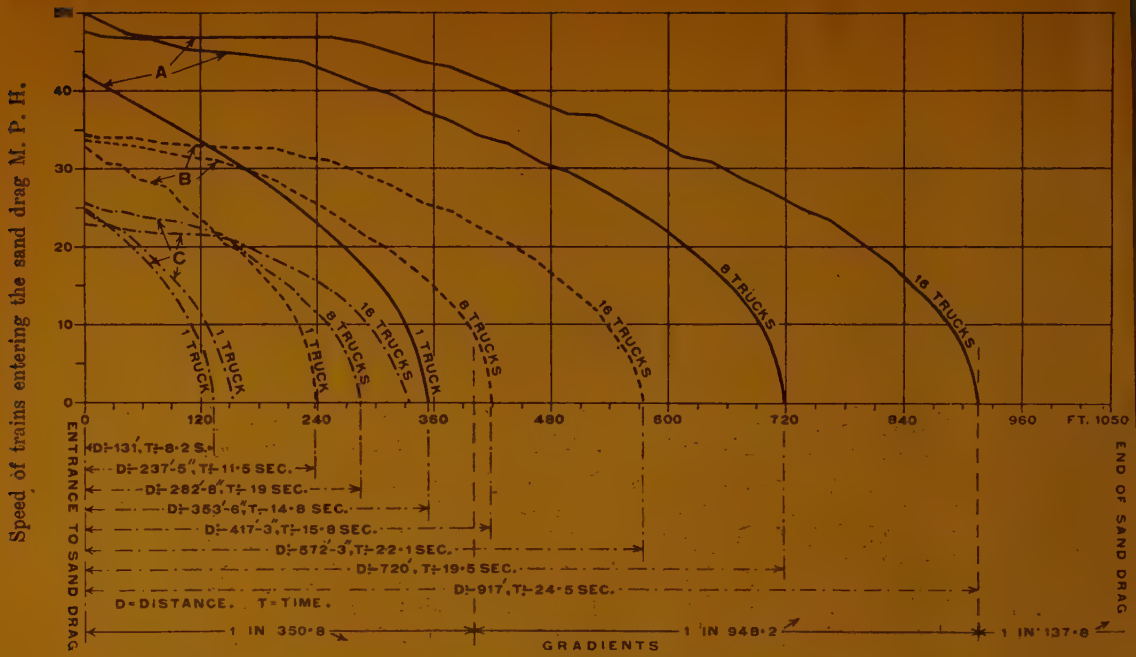


Fig. 13. — Retardation curves of sand drag in Waterloo Tunnel, Liverpool.

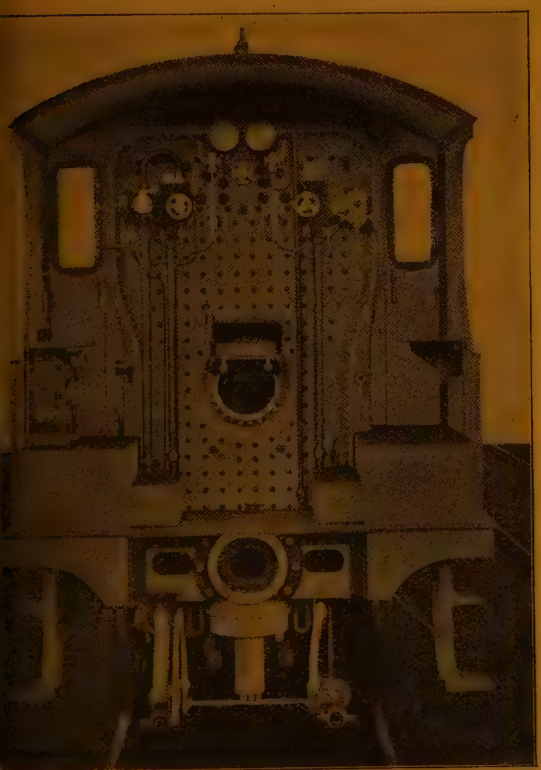
A = Speed curves for trains starting at 8 000 feet from entrance of the sand drag.
B = — — — 4 000 — — —
C = — — — 2 000 — — — —

Each truck loaded and weighed, 11 1/2 tons.

Fig. 14. — Locomotive, Camden & Amboy Railroad, U. S. A., 1845.

Early American 8 foot single. — Figure 14 illustrates the Camden and Amboy locomotive of 1845, which had a large 8 foot diameter driving-wheel at the end of the boiler, showing that the Crampton idea was not confined to this country.

Footplate views. — In order to show the difference between the footplate of a modern locomotive and those built many years ago, figure 15 has been prepared, which shows the footplate of Lancashire & Yorkshire Engine No. 1 400, built in 1899, and the footplate of engine No. 36 built by Messrs. Bury, Curtis and Kennedy for the Great Southern & Western Railway in 1848. It will be observed that there is no protection from the weather for the driver on the Bury, Curtis and Kennedy engine, and even later it was only usual to put a weather-board in front.



Engine No. 1400,
designed by the Lecturer, 1899.

Engine No. 36, Messrs. Bury, Curtis & Kennedy,
Great Southern & Western Railway (Ireland), 1848.

Fig. 15. — Footplate views.

I can well remember the time, about 1872, when Mr. Webb put the first cab on to a London & North Western engine. As these cabs were added to other en-

gines, much indignation was expressed by the drivers, who had from their daily exposure to the weather become very hardy, whereas when they worked on an engine with a cab they were kept much warmer while there, but were much more affected by the weather on account of the changes of temperature when they were off the engine.

Increase in size of locomotives. — Figure 16 shows two engines which I designed for the Lancashire & Yorkshire Railway, one No. 1 099 built in 1891, and the other, No. 1 400, built in 1899. So far as the mechanism is concerned, these engines are almost identical in design, but No. 1 400 was fitted with a large boiler, of which an illustration is shown in figure 17, which stood very much higher above the rails than had been the practice in this country before.

Looking back over the history, during a number of years, of the practice as regards the Lancashire & Yorkshire Railway, I have found that, speaking roughly every ten succeeding years has demanded a change, higher speeds and heavier loads having called for a much more powerful machine, and figure 16 shows the difference between engine No. 1 099 and No. 1 400, and is merely an illustration of this growth.

It is an amusing fact that when engines of the No. 1 400 class first began to run on the Lancashire & Yorkshire Railway, a very prominent director of one of the locomotive building firms of the country, who travelled in these trains every day, was asked by his fellow-passengers to come and see me with regard to them, because they could not believe that these engines were safe. I was, however, able to put such information in his hands as to convince his fellow-passengers that the high centre of gravity ensured better riding and a better use of the springs, which all made for safety, as contrasted with the days of the very early engines of the Bury, Curtis and Kennedy type, which had their boilers placed very low and used to waddle in such a way as to tend to burst the road.

I have thought it right to illustrate, figure 18, the largest passenger locomotives which are at the present moment being used upon the four groups of railways in this country.

These six illustrations are made out to the same scale, and give exactly the same kind of information with regard to each of the respective machines, so as to make a comparison easy and form a perfect record of modern practice. The engines illustrated are :

The London Midland & Scottish Railway . . .	4-6-0.	No. 8 Class.
— — . . .	4-6-0.	Claughton Class.
— — . . .	4-6-0.	Compound.
The Southern Railway	4-6-0.	No. 15 Class.
The Great Western Railway	4-6-0.	Castle Class.
The London & North Eastern Railway	4-6-2.	Pacific Class.

Several of the locomotives are of such over-all dimensions that no real practical increase can be made in their size in the future owing to the limitations of the structure gauge.

It is as well to remember that with us the limiting factors against very big loads are at present : the strength of bridges, the strength of the three-link coupling, and the absence on goods trains of continuous brakes.

The probable tendency with regard to future locomotives will be to use higher pressure in the boilers, as the outside cylinders of locomotives have already reached dimensions which cannot be exceeded on account of the station platforms projecting as far as the construc-

Fig. 16. — Engines Nos. 1099 and 1400.

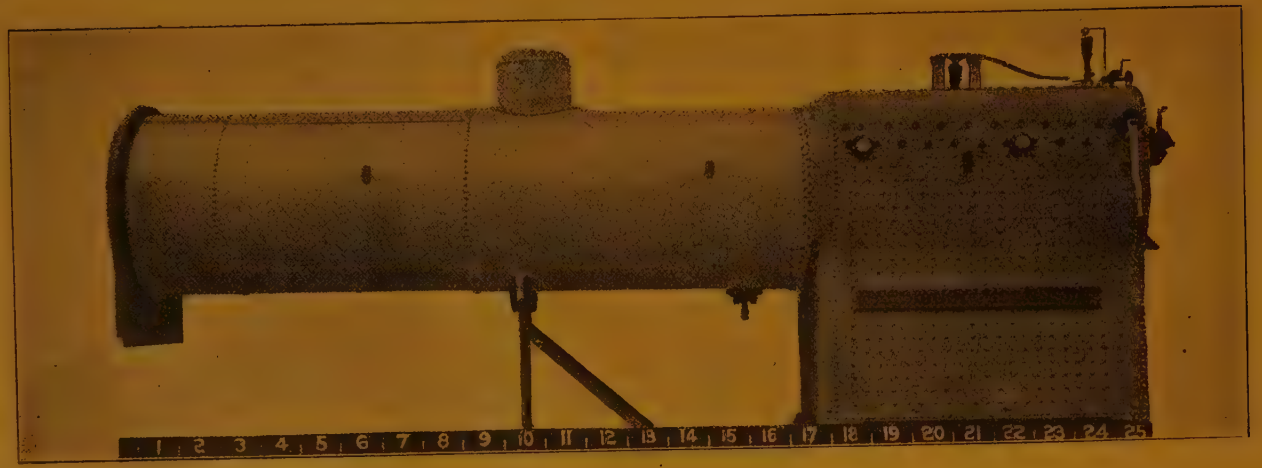
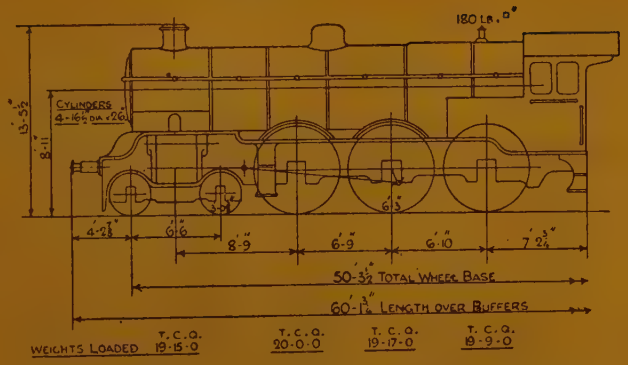


Fig. 17. — Boiler of engine No. 1400.

London, Midland & Scottish Railway.

4-6-0, class 8, superheated.



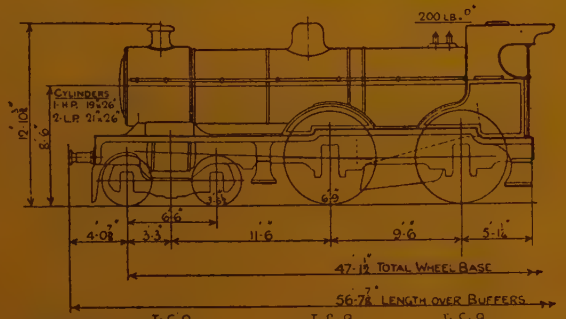
WEIGHTS LOADED	T.C.Q. 19-15-0	T.C.Q. 20-0-0	T.C.Q. 19-17-0	T.C.Q. 19-9-0

Engine loaded	79 T.	1 C.	0 Q.
— light	72 T.	12 C.	0 Q.
Tender loaded	40 T.	0 C.	0 Q.
— light	19 T.	11 C.	0 Q.
Engine and tender loaded	119 T.	1 C.	0 Q.
— — light	92 T.	3 C.	0 Q.

Tractive power at 85 %. B. P. = 29 470 lb.
Tender (6 wheels). — Water, 3 000 gallons ; coal 6 tons.

London, Midland & Scottish Railway.

Superheated compound passager engine.



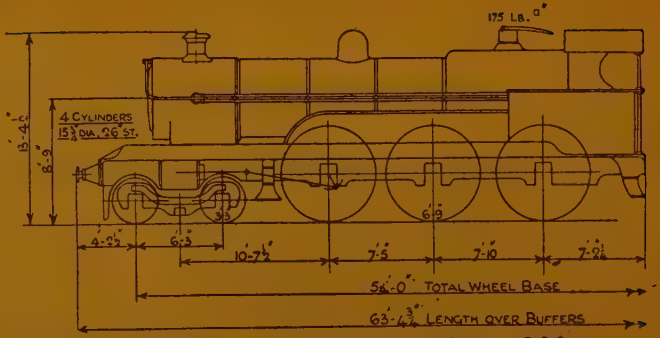
WEIGHTS LOADED	T.C.Q. 22-10-0	T.C.Q. 19-15-0	T.C.Q. 19-9-0

Engine loaded	61 T.	14 C.	0 Q.
— light	57 T.	9 C.	1 Q.
Tender loaded	42 T.	14 C.	0 Q.
— light	21 T.	11 C.	2 Q.
Engine and tender loaded	104 T.	8 C.	0 Q.
— — light	79 T.	0 C.	3 Q.

Tractive power at 85 %. B. P. = 22 649 lb.
Tender (6 wheels). — Water, 3 500 gallons ; coal 5 1/2 tons.

London, Midland & Scottish Railway.

4-6-0, Clanghton class, superheated.



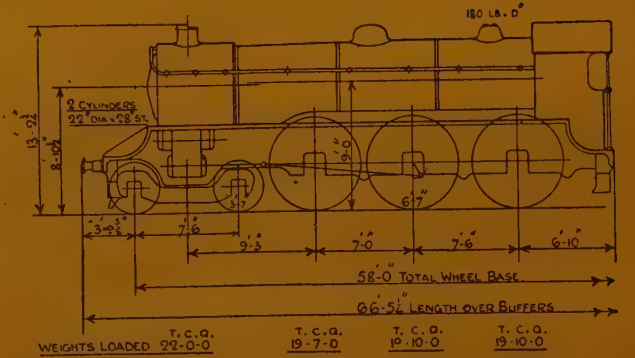
WEIGHTS LOADED	T.C.Q. 18-15-0	T.C.Q. 19-15-0	T.C.Q. 19-15-0	T.C.Q. 19-10-0

Engine loaded	77 T.	15 C.	0 Q.
— light	71 T.	15 C.	0 Q.
Tender loaded	39 T.	5 C.	0 Q.
— light	19 T.	2 C.	0 Q.
Engine and tender loaded	117 T.	0 C.	0 Q.
— — ligth	90 T.	17 C.	0 Q.

Tractive power at 85 %. B. P. = 24 130 lb.
Tender (6 wheels). — Water, 3 000 gallons ; coal, 6 tons.

Southern Railway.

No. 15 class, superheated.

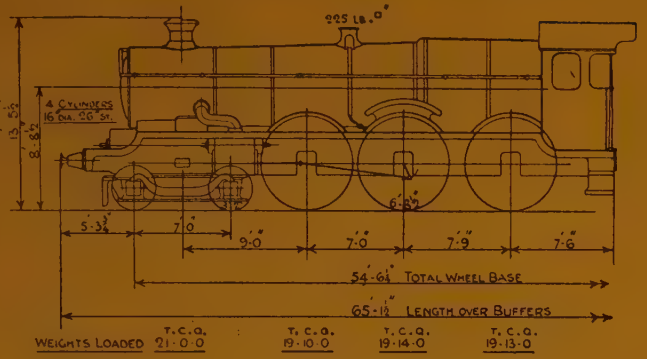


WEIGHTS LOADED	T.C.Q. 22-0-0	T.C.Q. 19-7-0	T.C.Q. 19-10-0	T.C.Q. 19-10-0

Engine loaded	80 T.	7 C.	0 Q.
— light	74 T.	8 C.	0 Q.
Tender loaded	57 T.	16 C.	0 Q.
— light	30 T.	18 C.	0 Q.
Engine and tender loaded	138 T.	3 C.	0 Q.
— — light	105 T.	6 C.	0 Q.

Tractive power at 85 %. B. P. = 26 246 lb.
Tender (6 wheels). — Water, 5 000 gallons ; coal 5 tons.

Great Western Railway. — Castle class, superheated.

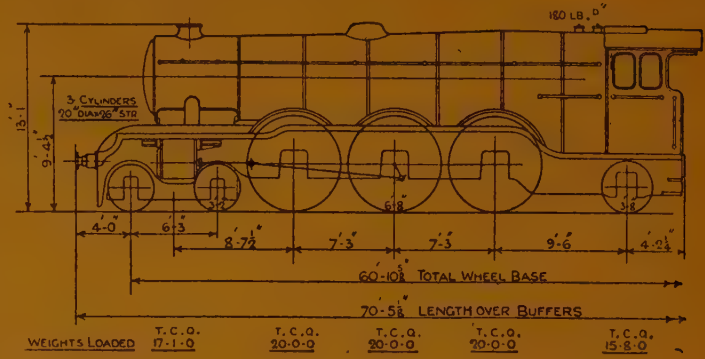


Engine loaded	79 T.	17 C.	0 Q.
— light	73 T.	15 C.	0 Q.
Tender loaded	40 T.	0 C.	0 Q.
— light	18 T.	5 C.	0 Q.
Engine and tender loaded	119 T.	17 C.	0 Q.
— — light	92 T.	0 C.	0 Q.

Tractive power at 85 % B. P. = 31 625 lb.

Tender (6 wheels). — Water, 3500 gallons ; coal, 6 tons.

London & North Eastern Railway. — « Pacific » class, superheated.



Engine loaded	92 T.	9 C.	0 Q.
— light	82 T.	9 C.	0 Q.
Tender loaded	56 T.	6 C.	0 Q.
— light	26 T.	7 C.	0 Q
Engine and tender loaded	148 T.	15 C.	0 Q.
— — light	108 T.	16 C.	0 Q.

Tractive power at 85 % B. P. = 29 835 lb.

Tender (8 wheels). — Water, 5 000 gallons ; coal, 8 tons.

Fig. 18. (*Continued.*)

tion gauge will admit. One means of getting over this difficulty, apart from other advantages, is to use the three or four cylinder engine.

With a view to seeing what can be done in higher pressures the Delaware & Hudson Railroad, assisted by the advice of Sir Alfred Yarrow, have quite recently designed and built a locomotive boiler with a large number of water tubes, the pressure being 350 lb. per square inch. This is illustrated in figure 19 (1).

The wearing capacity of the machinery of a locomotive, apart from the boiler, is very great, and it is very true to say that it far outlasts its capacity for haulage, which is brought to an end by the increase of loads.

The great reliability of the steam locomotive is illustrated by the fact that the failures are so few, and it is really a testimonial to reliability when you remember that the daily newspapers consider it such an unusual occurrence for an engine failure to take place that they make it the subject of large headlines. When you look also at the fact that there are 24 000 locomotives on the English railways and that the number of engine-miles run in 1924 was 398 000 000, you will appreciate that to run over 1 000 000 miles per day with only occasional failures is a very wonderful performance.

American locomotives. — In the United States the difficulties of increasing train loads are less than with us, and taking the Pennsylvania Railroad as typical of American practice we find that with passenger locomotives the tractive effort of their engines has increased between 1899 and 1923 by 301 %, their 4-8-2 class M.1. with 27 inch by 30 inch cylinders and 250 lb. boiler pressure, giving a tractive effort of 64 550 lb.

With their freight locomotives, between 1901 and 1922, the percentage of increase with the HC1s class, which has four cylinders 30 1/2 inches by 32 inches and a boiler pressure of 205 lb. per square inch, has risen 320 %, having a tractive effort of 135 000 lb., while their 2-10-0 with two cylinders 30 1/2 inches by 32 inches, with 250 lb. pressure, gives a tractive effort of 90 000 lb., or 213 % increase.

In all cases the mean effective pressure has been taken at 75 % of the boiler pressure.

Wooden-framed tenders. — As showing the desire to avoid possible injury to passengers, it may be of interest to know that John Ramsbottom told me that the reason why, on the London & North Western Railway, they made their tender frames of timber for so many years, was that, according to his view, the tender between the engine and the train should be the weakest part of the train, and that this should break up first in case of collision and thus save the passenger carriages. The idea seems to have been similar to that with regard to having a breaking spindle in a rolling mill.

Views of high speed in 1862. — Looking backwards some will recollect what was considered a wonderful run over sixty years ago at the time of what was known as the « Trent » affair, when Messrs. Slidell and Mason, two Confederate representatives, were taken from the British ship by the *San Jasinto*, a Federal ship, and made prisoners. This led to an incident on 7 January 1862 in locomotive running which was thought much of at the time when a special train was kept ready at Holyhead to carry the British representative to London. A run of 130 1/2 miles from Holyhead to Stafford was made by Ramsbottom's engine called « Watt », in two hours and twenty-five minutes, the average speed being 54 miles per hour and then the train was taken on 133 1/2 miles to

(1) Illustrations of this boiler have already been given in the number of February 1926, pp. 131 and 134, of the *Bulletin of the Railway Congress.*

Euston by one of McConnell's single-wheeled inside cylinder engines of what was known as the « Bloomer » Class, No. 372.

Modern high speed timing of trains. — Nowadays, however, we have arrangements such as those on the London, Midland and Scottish for running high-speed trains between London and Birmingham. The time between Willesden and Birmingham is scheduled to be 109 minutes for a distance of 107 1/2 miles, and it has been shown that on some occasions the journey has been done in 102 minutes, while on the Great Western Railway there are several instances of trains which are actually timed to run between Swindon and Paddington and Paddington and Bath at over 61 miles per hour.

Old-time heavy goods train loads. — It is recorded by Mr. Salt that a trial was made in August 1846, on the Manchester and Birmingham line, of a powerful engine made by Messrs. Sharp, Brother and Co. for the company, possessing several improvements, suggested by Mr. John Ramsbottom, the company's locomotive superintendent. A train of merchandise was drawn by this engine from Manchester to Crewe, which comprised ninety-seven wagons, the gross weight of which was 586 tons and the net weight of the goods 264 tons. The rate of speed was 15 to 25 miles an hour.

Again, under the heading « Monster Train » : on Saturday, 3 October 1846 a train of merchandise left Manchester for Crewe composed of 101 wagons. Its gross weight was 600 tons and its length 1 550 feet. The distance, 30 miles, was accomplished in two hours and nine minutes, being at the rate of 14 miles an hour over gradients varying from 1 in 377 to 1 in 880. The engine was made by Sharp & Co. and accompanied by Mr. Beyer, Mr. Ramsbottom and Mr. Salt.

It will be observed that the first train mentioned gives an average load of merchandise per wagon of 2.7 tons in the ninety-seven wagons used, and it is instructive to look at the modern returns produced in the form presented by the Ministry of Transport, as here it will be found that the average wagon load in Great Britain for merchandise is 2.92 tons, so that we have not made much progress in the load per wagon. When we find these modern returns showing that the average number of wagons per train is only thirty-five, we see how very misleading a system of average figures may become when it is well known that there are many goods engines in this country hauling loads of 1 000 to 1 200 tons.

Lubrication. — Methods of lubrication have been immensely improved, and, with the certainty that all moving parts could be properly lubricated, the possibility of high speeds has increased. I remember in the very early days that Mr. Ramsbottom produced what I believe was the first form of displacement and sight-feed lubricator. As I was employed to assist the draughtsman who was trying the experiment, I have a vivid recollection of the way in which it was done.

To the outside cylinders of one of his « Lady of the Lake » class locomotives he fitted two glass lubricators, which were nothing more than two old-fashioned egg-ended soda-water bottles, which were attached to the underside of the cylinders by means of brass unions. The amount of oil which these contained on leaving Crewe was recorded, and they were carefully examined on arrival at Euston. This experiment led to the creation of the spherical form of brass lubricator which was put on the side of smoke-boxes of London & North Western engines, but which was first of all attached underneath the steam-chests as illustrated in Zerah Colburn's book on Locomotive Engineering.

With lower pressures than we have today, lubrication was a less difficult mat-

ter than it is at the moment, hence there has been a widespread tendency to use piston-valves instead of any of the flat-faced D valves. I am not aware that anyone has recorded the results of any experiments with piston-valves to show the force required to move them, but the experiments which I tried in 1888 on the Great Southern & Western Railway are recorded in the Proceedings of the Institution of Civil Engineers of 18 December 1888.

In these experiments it was found that flat brass valves measuring 16 1/2 inches by 10 inches with a steam-chest pressure of 139 lb. gave a resistance to movement at mid stroke of 1 321 lb., giving a coefficient friction of 0.068.

Permanent way. — Some idea of the prices which had to be paid for work in the year 1827, before the Liverpool and Manchester Railway was actually opened, is given in figure 20, this being a copy of an estimate signed by George Stephenson himself and dated 28 February 1827.

How great have been the changes in permanent way I think might be illustrated by quoting some facts which were given in a report made by Mr. Hawkshaw (afterwards Sir John Hawkshaw) to the Lancashire & Yorkshire Railway in 1850, though it must, of course, be understood that there were many forms of track which were used by the earliest railways long before this. The illustrations which are reproduced in figure 21 show that there were great varieties of permanent way in use, varying in weight from 46 lb. per yard up to 85 lb. per yard, and of many different sections. These great varieties of sections gradually disappeared, and a form of double-headed rail weighing from 80 to 85 lb. per yard was very generally adopted.

Of course, the idea underlying this double-headed rail was that when one head had worn out the rail could be turned upside down and the other head brought into use, and there must be many of the senior members of this Institution who recollect what the effect of this turning was. The rail became seriously chair-galled on the lower head, and when the time came that the upper head was worn and the rail was turned, there were a series of depressions in what now became the upper head which resulted in a tremendous rattle being created in the train as the wheels went over these depressions, which were about a yard apart.

Then came the rail which is almost universal in England to-day known as the bull-headed rail, where some of the material which used to be put in the bottom head was placed in the top head. The superior material of to-day enables that upper head to be worn down to the utmost limit without getting any unevenness of track.

The earlier rails were in many cases not more than 15 feet long, and this was no doubt due to many of these rails being made of iron, and to the fact that rolling mills had not arrived at their present state of perfection. When steel rails were introduced, ingots from which they are rolled could be made of any reasonable size, and powerful rolling mills were capable of dealing with any section.

Nowadays a rail weighing 95 lb. to the yard and 45 feet in length is very commonly used on British railways, but on the London, Midland & Scottish a very large mileage of 60 foot rails will be found.

As an illustration of the endeavour of some of the earlier engineers to get long rails and save the number of joints, I found when I was on the Great Southern & Western Railway of Ireland that the civil engineer who had had charge of their permanent way department a good many years before made a practice of having the iron bridge rails which they used brazed together at the ends so as to make three rails into one length.

Estimate

	£
10 Miles of Malleable Iron Railway.	8250 .. 0 .. 0
Cast Iron Chairs for ditto	1760 .. 0 .. 0
Stone Blocks for ditto	3520 .. 0 .. 0
Laying the Way	2640 .. 0 .. 0
2 Permanent Engines	4700 .. 0 .. 0
Rollers for the Inclined Planes	594 .. 0 .. 0
Ropes for do	550 .. 0 .. 0
Keys and Pins for chairs	680 .. 0 .. 0
40 Small Waggons	240 .. 0 .. 0
40 Large do	960 .. 0 .. 0
Forming Inclts and Excavations	8331 .. 1 .. 6
Carriage of Rails, chairs, & blocks to different parts of the Line	2000 .. 0 .. 0
Bridge	300 .. 0 .. 0
Culverts	500 .. 0 .. 0
Fencing	880 .. 0 .. 0
Depôts at each end of the Line	800 .. 0 .. 0
Agencies & Incidentals	1000 .. 0 .. 0
	£37905. 1. 6

Liverpool Febr 28th 1827

Geo Stephenson

Fig. 20. — Permanent way. — George Stephenson's estimate of prices, 1827.

Fig. 21. — Sections and weights of rails per yard,
Lancashire & Yorkshire Railway, 1850.

As different parts of the railway had to be relaid these rails used to come in as scrap for shipment to South Wales, where the different works were glad to receive them as good old iron, but we received grievous complaints from the managers of the works that we were sending brass to them mixed up with the rails, which spoiled their furnace bottoms. These rails very seldom broke at the brazed joint. So far as the brazed work was concerned, resting as it did upon cross sleepers, it made it difficult to get a satisfactory joint at the ends where it usually rested upon what was known as a Harty chair, which was formed of an inverted « T »-shaped section.

At the date of the Hawkshaw Report already referred to (1850), there were on the Lancashire & Yorkshire Railway no engines which weighed more than 24 t., while there were seventy-six which weighed less than 20 tons, twenty-eight that weighed less than 15 tons, and ten that weighed less than 10 tons. It will thus be observed that no serious demand was made on the permanent way such as occurs to-day with modern engines which weigh without their tenders in many cases well over 70 tons, and in one prominent instance 92 tons 9 cwt., and have weights on a single pair of wheels of from 19 to 20 tons.

The changes which have taken place since George Stephenson's time, which have enabled high speeds combined with safety to be made, are very numerous. Facing points have been so well constructed that there is no risk with regard to them. In the earliest days the points and crossings as we know them to-day did no exist, but movement from one line to another was made by « shifting rails ».

I have not seen any absolutely reliable record as to who invented the first set of points, but the idea has been attributed to Sir Charles Fox, and it is easy to understand how, in the earliest days of their use, they were looked upon as being somewhat dangerous, but as time has gone on these have become so perfect in their fitting, have been so securely locked to prevent movement at the wrong time, and have withstood the severe work of high-speed trains with heavy locomotives passing over them, that they have proved themselves to be quite as safe as any part of the permanent way, and the old idea that a pair of facing points contain an element of danger has long passed away. The points are now absolutely secured by the facing point lock, and where it is necessary in other places locking bars are used, which prevent any kind of movement of the points so long as there is a railway vehicle standing on them.

The balancing of locomotive moving parts and of their wheels has reduced the punishment of the permanent way to a minimum, and the balancing of carriage wheels, which was not understood for some time, has contributed to the easy riding of the coaches.

Post office pick-up. — As a method of saving delay, one of the most useful inventions produced in 1838 was that of Mr. John Ramsay, an officer of the Post Office, whose apparatus was used on a letter-sorting carriage between Birmingham and Liverpool for exchanging mail bags *en route*. This apparatus was later on improved by Mr. John Dicker, also of the Post Office, and mail coaches are still fitted with this arrangement, which is almost to the original design. This invention of the means of dropping the mails and of picking them up has made the non-stop runs of mail trains an easy matter, and enabled many country towns to get an earlier delivery and a later collection of letters than could possibly have obtained before.

Again, as a time-saver the same kind of idea, modified to suit the requirements, was used for the purpose of enabling tablets or train staffs on single lines of railway to be exchanged without

stopping the train. I first saw this on the Callander and Oban line. Later on, somewhat similar apparatus was produced by Mr. James Manson on the Great North of Scotland Railway, and again, a modification produced by Mr. A. Whitaker was used on the Somerset and Dorset line in 1905.

Water troughs. — One of the most important inventions for time-saving on the railways was that produced by John Ramsbottom when he made the first set of water troughs, which were laid on the Chester & Holyhead Railway. They were 441 yards long and enabled a train going at 60 miles an hour to pick up 5 tons of water in a quarter of a minute. A Paper, giving the details of these troughs, was read before this Institution by Mr. John Ramsbottom in January 1861. The Ramsbottom water troughs had a very great influence on the speed of trains, not only for passenger trains but also for heavy goods trains. It is a curious fact that these were not appreciated very much by the English railways although, as stated above, Ramsbottom dealt with them in the early « Sixties ».

The Americans, however, on the Pennsylvania Railroad put them in with great advantage to themselves, but it was not until I asked my directors on the Lancashire & Yorkshire Railway in 1886-1887 to put them in upon that line, where there are now a number of them, that they were adopted by any other English railway. This practice was followed later on by several other railways in this country.

As to the future of railways, everyone is aware of the way in which railway traffic has been profoundly affected by the use of the modern motor-vehicle, whether for passengers or for goods, and while it should be remembered that the use of the motor-car in England only dates back about 30 years, the increase in the number of vehicles used has been stupendous.

It seems probable that the swelling volume of motor traffic will create its own blockade, and that for some services the railways will again be called upon to handle certain classes of traffic, and we shall find motors competing with one another to collect and deliver traffic at railway stations and avoid the intolerable delays on the high roads near the great towns.

The congestion which is likely to take place on roads is perhaps best estimated by the fact that there were at the end of last November 1 242 000 motor-vehicles of all kinds which had been licensed, and these work on a total road mileage in England, Scotland, and Wales of 178 000 miles, which thus give 6.98 machines to the mile.

The rate of addition to the total stock of motors may probably be estimated at about 200 000 a year, having regard to the fact that the increase in 1924 was 176 000 over 1923; therefore, if this rate of increase continues for ten years, there will be about eighteen vehicles to the mile, even if equally distributed over the whole country, whereas the congestion in and around our great towns will be something which no traffic authority has yet shown its capacity to deal with.

On the other hand the railways have 20 171 miles of track operated by 24 000 locomotives, slightly over one to the mile, thus giving much wider spaces into which traffic can be placed.

It is probable that George Stephenson never contemplated the effect which railways would have, apart from the carriage of passengers and goods, in finding an enormous amount of work for all sorts of manufacturers in this country. The railways are very great consumers of stores, and whether it is steel or iron, brass or copper, timber or cloth, gas or oils, which are required in very large quantities, the companies have become

great supporters of home industries, involving the expenditure of millions of pounds every year.

Nor is it likely that George Stephenson would have imagined that railway employment would require a staff of 700 000 men, of which about 150 000 are skilled mechanics.

There are very few things in which railways do not help the manufacturing industries of this country, and it would almost seem as if Mr. Rudyard Kipling was right when he recently said :

« Everything in life from marriage to manslaughter turns on the speed and cost at which men, things and thoughts can be shifted from one place to another. »

APPENDIX.

Pennsylvania Railroad system,
Operating Department,
Philadelphia, 19 January 1925.

Sir John A. F. Aspinall.

DEAR SIR,

Answering your letter of 5 January, with reference to the different track gauges in use in this country about 1872, the situation at that time, so far as the Pennsylvania Railroad was concerned, is described in the following extracts from the Annual Reports for the years 1868 and 1869 :

« (1868). By some oversight, local considerations or a limited conception of the important part that railways were to play in the movement of the internal commerce of the country, Pennsylvania and Ohio have each been placed between two different railway gauges which for a long time forced transhipments of freights at their connexions.

« The Pennsylvania Railroad Company has, both on its eastern and western connexions, a gauge of 4 ft. 10 in., and Ohio, on each side of her, a gauge of 4 ft. 8 1/2 in. — the latter being the prevailing gauge north of the Ohio and James Rivers; while south of these the gauge of 5 feet prevails, which should have been adopted originally as the uniform gauge of the United States.

« To obviate the inconvenience, the increased cost, and the additional capital required to move traffic, in consequence of these frequent transhipments, from a difference of gauge of only 1 1/2 inches, broad tread wheels were introduced for through traffic, which has, to a large extent, overcome these evils. Owing, however, to the great oscillation of the cars on the wider gauge, the Ohio lines insisted upon a play upon the narrow gauge, that added materially to the cost of hauling upon the gauge of 4 ft. 8 1/2 in.; to remedy which the gauge of your road has been changed to 4 ft. 9 in., and the Ohio roads have been or are being changed to 4 ft. 9 1/2 in., leaving but a difference of 1/2 inch, which it is presumed that time will reduce to uniform gauge of 4 ft. 9 in. »

« 1869). In our last annual report the diversity of railway gauges between the East and West was alluded to. Since that period all of your immediate Western connexions have reduced the gauges of their lines from 4 ft. 10 in. to 4 ft. 9 1/2 in., which, when their machinery is adapted to it, will be further reduced to 4 ft. 9 in. — the present gauge of the Pennsylvania Railroad ».

In 1892 the Pennsylvania Railroad adopted a 4 ft. 8 1/2 in. gauge as standard for passenger tracks and 4 ft. 9 in. for freight tracks. The present gauge for all tracks is 4 ft. 8 1/2 in., in accordance with the standard gauge established by the American Railway Association in 1897.

As to the early gauges of other American railroads : The first roads built in Eastern States conformed to the English gauge of

4 ft. 8 1/2 in. Later, however, gauges were adopted ranging from 3 feet to 6 feet. The States of New Jersey and Ohio established by law a gauge of 4 ft. 10 in.; 5 feet was fixed as the gauge of the South Carolina Railroad, and was adopted by its connecting roads, and this extended generally throughout the South; 5 1/2 feet was established for Missouri and Canada roads; and 6 feet as that of the New York and Erie and the Atlantic and Great Western. By 1880 the Northern lines had pretty generally come to a uniform standard of 4 ft. 8 1/2 in., or the interchangeable standard of 4 ft. 9 in., to facilitate the convenient interchange of cars and traffic.

During the interval from 1880 to 1888 many of the narrow gauge (3 feet) roads were changed into standard gauge lines, or a third rail laid down which supplied a standard gauge track, and nearly all the Southern lines which formerly maintained a 5 foot gauge narrowed their tracks (1886), the new standard generally adopted being 4 ft. 9 in.

In 1897 the American Railway Association, in view of the importance of the proper adjustment of wheel and flange gauges to the track, and therefore the necessity for a standard track gauge, adopted the following resolution :

« That 4 ft. 8 1/2 in. shall, hereafter, be the standard gauge of all tracks owned by the railroad companies forming this Association. This gauge shall be the shortest distance measured between the inside of the heads of the two rails forming the track. »

Yours very truly,

(Signed) J. T. WALLIS,

Chief of motive power.

MISCELLANEOUS INFORMATION

[625. 144.4 (.41)]

1. — Railway track-relaying machine.

Figs. 1 to 13, pp. 767 to 771.

(From *Engineering*.)

By the figures 1 to 13 we illustrate a track-relaying machine, designed and patented by Mr. A. W. Bretland, Deputy Chief Engineer of the Great Southern Railways of Ireland. The sole rights to manufacture this track-layer have been acquired by Messrs. Herbert Morris, Limited, of Loughborough, who have retained the services of Mr. David L. Rutherford, M. Inst. C. E., late Chief Engineer of the Furness Railway, in a consulting capacity. In essentials, the machine is an adaptation to track-laying, of the system of block laying, long standardised in pier and harbour work. Sections of track, one rail length long, are assembled complete in the store yard, where every facility can be provided for the work. These sections of track are, for transport to the site of operations, loaded on to a materials train. On this train is mounted the equivalent of a « Goliath » which runs on rails secured to the trucks, and is used to feed a cantilever crane, corresponding to a « Titan », installed at the head of the train.

The complete system comprises a depot, a materials train and a track-layer. At the depot all materials are dealt with by power in bulk, and new track is assembled and old track dismantled under shop conditions. The materials train consists of bogey wagons of a capacity to suit individual requirements. Along the train runs the electrically operated trolley for moving new material to the track-layer, and, when working on a relaying job, for receiving from it and carrying back to the materials train the old material picked up by the track-layer. When operating on track-relaying work, the track-layer, attached to one end of the materials train, lifts out the old material and places it on a wagon for the train trolley to remove. It then takes a length of new material from the train trolley and lays it on the formation from which the old length was removed. This operation is continued, the train moving forward over the old track, until all the new material has been dealt with, and a corresponding quantity of old material loaded on to the materials train. The train is then ready to return to the depot. It will be seen that during each working spell the train has taken all the new material to the site, and, by means of the track-layer, it has relaid the permanent way and loaded up and returned to the depot all the old materials. Powerful electric lighting is installed for night work.

A general view of this train with the two cranes mentioned, is reproduced in figure 1, where a complete track section is shown suspended from the cantilever crane. The train trolley, which corresponds with the « Goliath » used in harbour works, can be seen near the centre of the view, and behind it comes one of the trucks loaded with the completely assembled track sections. The train trolley can pass from end to end of the train, and is built high enough to straddle the after end of the cantilever crane, but sufficiently low to clear the loading gauge of the railway. Both the cranes are operated electrically from current supplied by a portable generating set of 5 H. P. rated capacity. This is mounted on a brake van at the end of the materials train. This, it should be stated, may be either pushed, or pulled, from the end of the

Fig. 1.

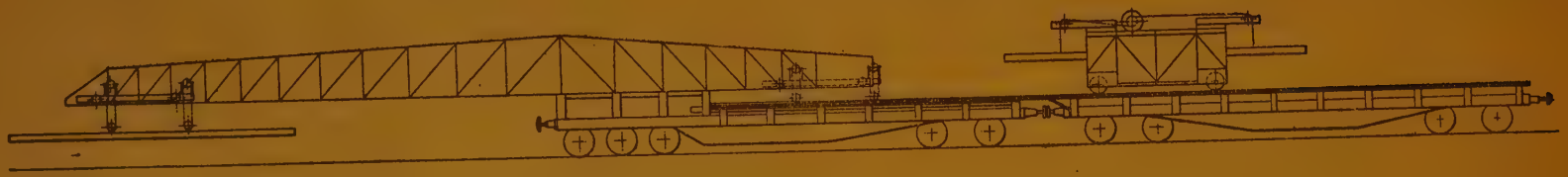


Fig. 2.

Fig. 3. — Bale for picking up a complete length of track.

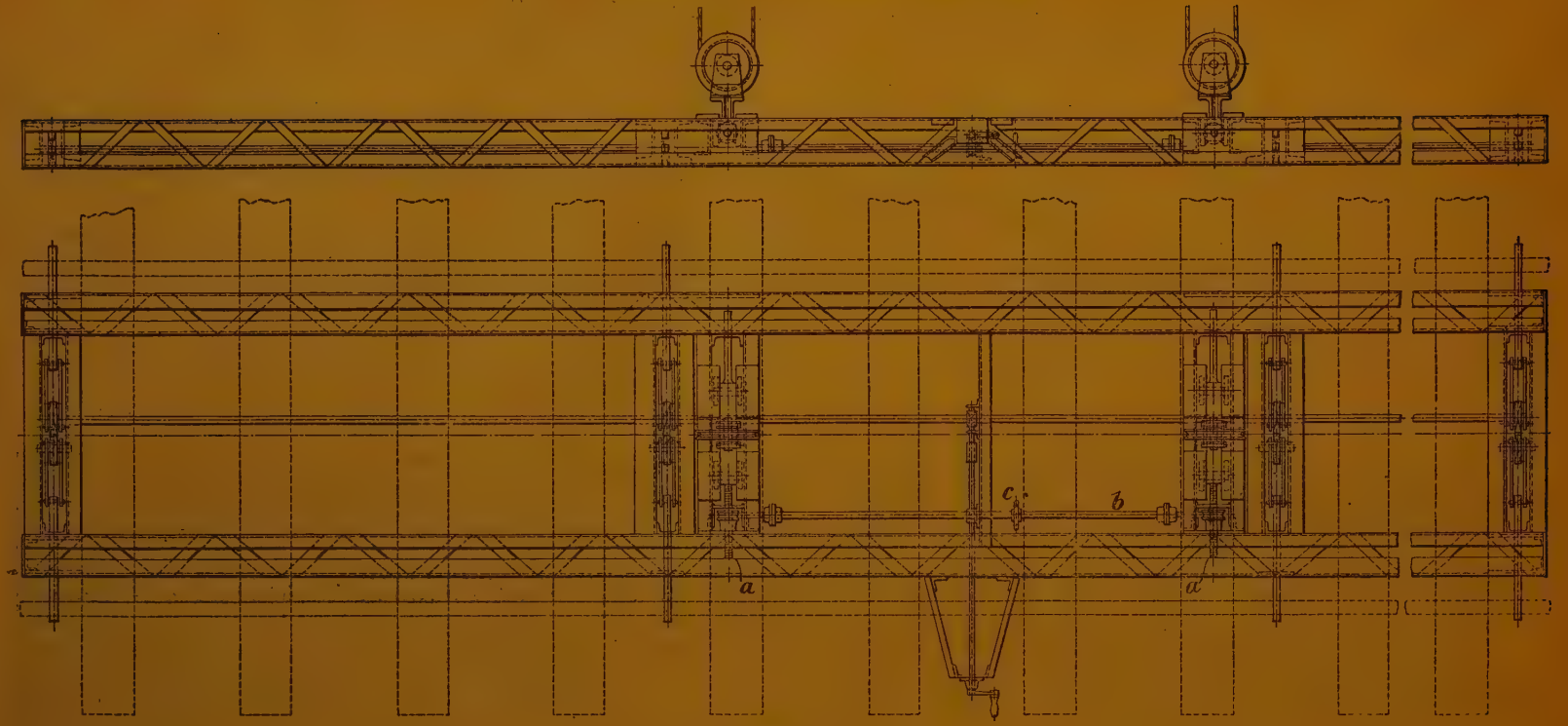


Fig. 4.

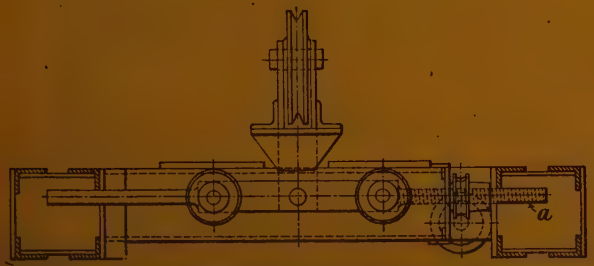


Fig. 5. — Section showing gear for varying centre laterally.

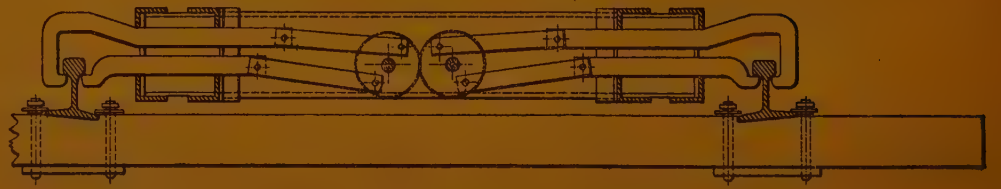


Fig. 6. — Section showing gripping dogs.

section to the site of the relaying operations. On arrival there the method of relaying is as outlined above. With 45-foot rails, the rate of relaying is 120 to 150 yards per hour, but with 60-foot rails, the speed rises to 200 yards or more per hour. No difficulty has been found in working between platforms, or retaining walls, or through bridges. After new material has been cleared from one truck, this becomes available for the reception of the old.

From the above brief sketch, it will be seen that hand labour is reduced to a minimum, and, moreover, that the fixing of the rails to the sleepers becomes a shop job instead of a field job, and can thus be conducted both more conveniently and expeditiously. As a result, total labour costs have been halved. It is obvious that for the most effective operation of the track-layer, when used for relaying work, possession of the road must be obtained for some period, either by day or by night. The longer the periods of possession the more effectively will the machine operate. The standard methods of track relaying have, it is true, been brought to a very high degree of perfection, but in essentials they are the same as 80 years ago, when rails weighed less than a third of what some do to-day. Nevertheless, it is still the usual practice to handle them during relaying operations, entirely by muscular power. Human muscle is the most expensive of all prime-movers, and its replacement by power justifies a great effort by the traffic department to arrange for the occupation of a track for the time required. The fact that the machine can be operated efficiently at night reduces the difficulties involved.

Characteristic views of the cantilever crane are represented in figures 7 and 8, which show respectively the leading and trailing ends. The general proportions and the amount of overhang provided, will, however, be better gauged on reference to figure 2. Views of the train trolley are reproduced in figures 9 and 10, whilst figure 11 shows the crane used at the stores yard, for loading and unloading the materials train. The sections of track are piled one above the other, on the trucks.

An important element in the outfit is the lifting frame or « bale », which replaces the hook of an ordinary crane. There are some slight differences in the « bale » used for the cantilever trolley, and that for the train trolley, but both are similar in essentials. That for the former is illustrated in figures 3 to 6. As shown in figure 3, it is suspended from the cantilever trolley at two points, and as will be seen from figure 4, it is provided with four sets of dogs for gripping the rails. The arrangement by which these dogs are closed on to the rail is illustrated in figure 6. The mechanism is operated by the handle to be seen in figure 4, which, by means of a worm gear, driving the longitudinal shaft shown, opens or closes the whole set simultaneously. Provision is made for traversing the track section laterally, so that it can be lowered into place truly aligned with the rails already laid. To this end, the lifting tackle is not secured directly to the « bale », but to slides which can be traversed across the « bale » by the screws *aa* (figs. 4 and 5). The nuts for these screws have worm wheels cut on them, which are driven by the shaft *b* and the hand weel *c*.

The trolley for the cantilever is built sufficiently low to be well clear of the upper lateral bracing of the cantilever. It is provided with independent traversing and lifting motors, and the latter is fitted with a powerful brake. Current is picked up from conductors fixed along the side frames.

The « bale » for the train trolley has a slightly different provision for lateral adjustment than that described above, but the difference is in detail only. In this case the traverse in question is controlled by the motorman, who travels with the train trolley in one or other of two cages, and it is necessary, therefore, that he should be able to work the mechanism from either position, and to do this readily whatever the level of the « bale ». The gear is accordingly driven by one of two endless chains which hang down near the motorman's cage and within his easy reach. As shown in figures 12 and 13, the « bale » for the train trolley is provided with a four-point instead of a two-point suspension. With this

Fig. 7. — Cantilever crane lifting a complete length of track.

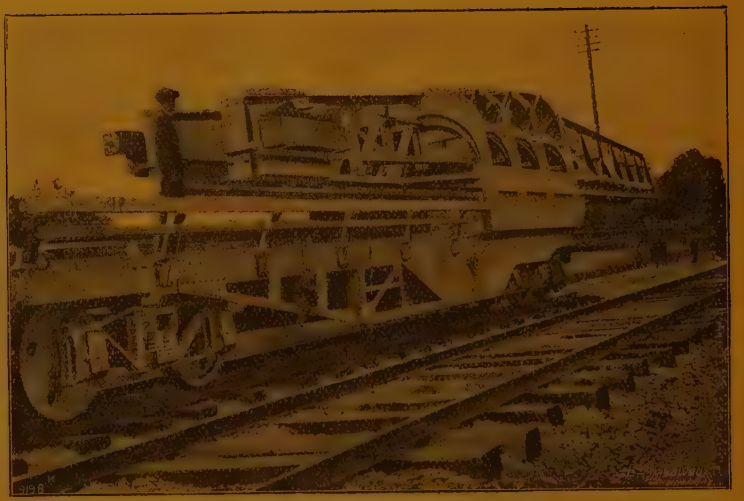


Fig. 8. — View of after end of cantilever crane.

Fig. 9.— Train trolley carrying track section ready for delivery

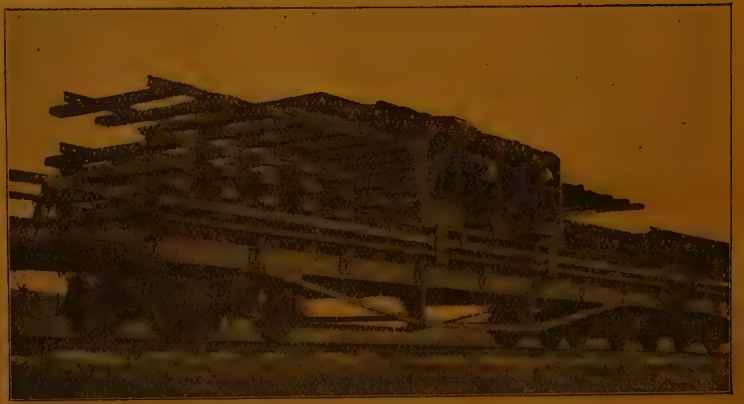


Fig. 10. — View of train trolley lifting track section from pile on car.

Fig. 11. — View of travelling crane in store yard showing « bale » used for handling the track sections.

Fig. 13.
End view of train trolley and « bale ».

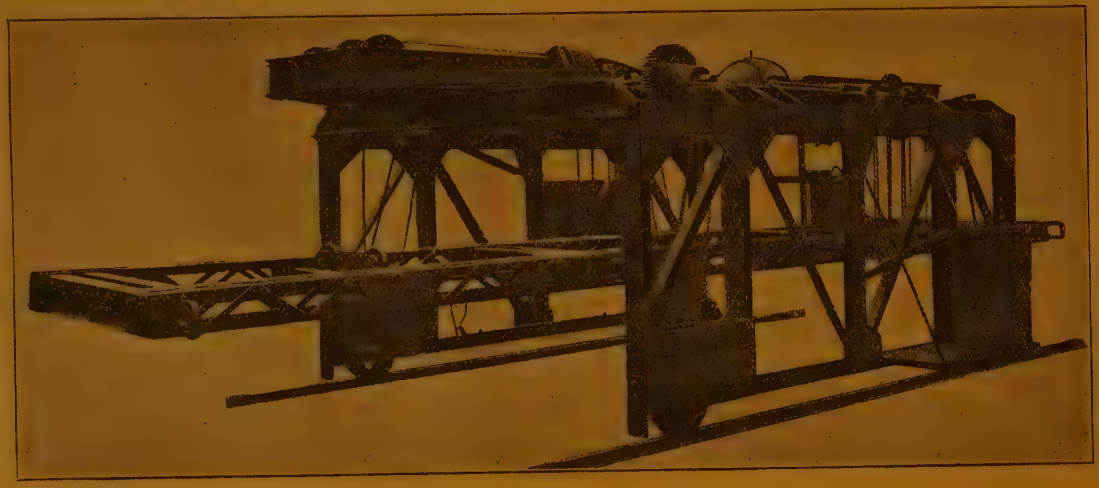


Fig. 12. — Train trolley and « bale ».

arrangement side tipping is impossible and a level lift assured, thus economising the space required for a clear lift.

The train trolley runs on rails carried on brackets bolted to the car bodies. The wheels have a double tread. The object of this is to facilitate the passage of the trolley from one car to another. The bridging piece spanning the gap between the bearer rails does not align with the latter, but is clamped to one side of them, and on traversing this bridge the wheel runs on the second of the two treads. All four wheels are driven by means of chains.

The two current collectors are, of course, at opposite ends of the train trolley. They are forced by springs into contact with the conductor rail. These rails are supported from the same brackets as the carrier rails and are insulated by wood.

It will be noted that the train trolley is provided with two folding cages, which in normal position are both folded up within the loading gauge. When actual laying or relaying is in progress, the cage on the side clear of the 6 foot way is unfolded for the use of the operator. There are, of course, dual controls, one to each cage. The operator has complete control of the gripping and traversing of the bale, and is able to pick up and deliver the track sections without any additional assistance. The motors, reduction gears, and starting resistances are all mounted on the top framing of the train trolley but are, of course, kept sufficiently low to clear the loading gauge.

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625 .143.5 (.941)]

2.— A new dogspike introduced in Western Australia.

Figs. 14 to 19, p. 773.

(*The Railway Gazette.*)

We have received from the Western Australian Railways Department particulars of a new type of dogspike which has been invented by Mr. E. F. Lenz, an engineer employed on the railways. In a land of such vast distances and sparse population, track maintenance costs have naturally to be kept to an absolute minimum, and keen interest is consequently taken in methods of preserving and extending the life of sleepers. The *Lenz* spike is the outcome of an invitation to the staff to co-operate in this direction. The device has been patented, but further particulars will gladly be supplied by Mr. W. Milligan, care of the chief engineer of Way and Works, Perth, to those interested.

The spike and wedge are shown in the accompanying figures. Figures 14 and 15 show the spike, the shank of which may be manufactured from either round or square sections. Figures 16 and 17 show the wedge, which can be stamped as in figure 16 or sheared from a rolled section as in figure 17. Figure 18 illustrates the spike and wedge as first driven. It will be observed that the wedge has only been driven sufficiently for its point to be deflected from the curved offset on spike into the timber. On account of the slight deflection, the wedge is prevented from working up (although it can be drawn very easily), and it is impossible for the spike itself to lift. The portion of the wedge above the sleeper is in reserve for taking up any future slackness until it is fully driven, as shown in figure 19.

To withdraw the spike, the wedge is first extracted by means of a short bar, and the spike is then lifted with the same bar.

An advantage which the *Lenz* dogspike has over all other types, and which makes it absolutely non-liftable under track conditions, is that the upward forces which lift other spikes are nullified by means of the double-wedge action of the *Lenz* spike and are diverted into horizontal pressures, which are resisted by the full compressive and shearing

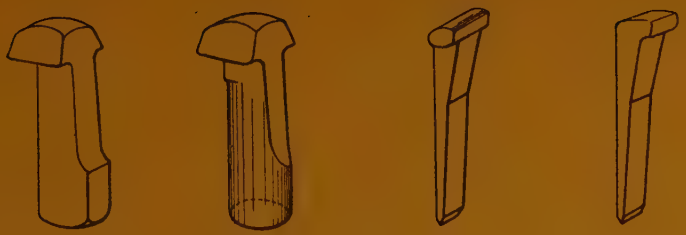


Fig. 14. Fig. 15. Fig. 16. Fig. 17.

Examples of spike and wedge construction.

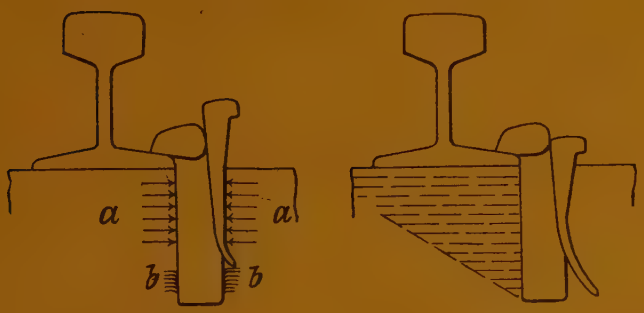


Fig. 18. Fig. 19.

Spike and wedge applied in service.

strength of the timber in a direction parallel with the fibres, as shown at *a*, *a* in figure 18, whereas other spikes are secured solely by the frictional resistance offered by the compressed portion of the ruptured fibres immediately surrounding the spike as at *b*, *b*.

Over 4 000 of these spikes were severely tested on the Government railways, mostly on sharp curves and in old holes where the ordinary spikes would not longer hold, for well over three years, and they are still as effective as when driven.

From numerous tests it has been found that the wedge will not have the slightest vertical movement from pressure brought to bear on the spike. Should the rail be removed and the spike be driven out by means of a heavy hammer and drift, the timber will only fail on the side *opposite* the wedge in a manner shown in figure 19, the wedge remaining intact; as a failure in this manner is impossible under track conditions, it emphasises the great security offered by the *Lenz* dogspike.

The *Lenz* dogspike gives a maximum of efficiency with low maintenance costs, the spike-killing of sleepers is eliminated, and other troubles due to loose spikes are reduced to a minimum.

[625 .143.4]

3. — The fracturing of fish-plates,

By N. GARRETT SMITH.

Fig. 20, p. 775.

(*The Engineer.*)

Although a few references to the fact can be found, it does not appear to be generally recognised that the majority of fractures of fish-plates begin at the top edge. The author has recently had an opportunity of examining a very large number of broken fish-plates from one of the railways in India, in almost all of which the fractures had started from the top edge, and in the following note proposes to discuss the reasons for this type of failure and its effect upon the general design of fish-plates.

In the plates examined by the author failure was only partial, the crack starting from the middle point of the top edge and finishing near the neutral axis, clearly indicating negative bending stresses (1). With tensile or shear stresses as the cause of failure, fracture would generally have been complete. The defective plates were found under all conditions, on straights and on curves, with cast iron or wooden sleepers and even where there was little or no creep. They were 26 inches long with four bolt holes spaced at 6 inches pitch. (The British standard fish-plate for four holes is only 18 inches long.) Some had only a very small flange reinforcing the bottom edge, other a big flange, and a few had in addition a slight vertical protruding foot. They were supplied from various different sources, being both of English and of Indian manufacture.

The stresses in a fish-plate.

The design of fish-plates has generally been based on the assumption that the maximum bending stresses would be imposed when the load was vertically over the joint. The bottom edge would then be in tension, and it has therefore, in some designs, been strengthened with a heavy horizontal flange, and occasionally even with an additional vertical flange on the end of the horizontal one. In fact, many different kinds of designs have been introduced and tried with the object of stiffening the joint. The following considerations will show the fallacy of this idea.

Experience has shown that failure, whether in plain or angle plates, nearly always starts from the top edge, which must therefore have been in tension. How this may occur will be readily realised from a study of track depression curves. It will be found that the sleepers, the ballast and the road bed below are not rigid supports, but are elastic and capable of considerable depression. The depression of a rail between sleepers is comparatively slight and almost negligible; that is, the maximum bending moment in a rail is practically the same whether the load is over or between sleepers.

From the track depression curves the relative bending moments can easily be estimated. In rails they would be inversely proportional to the radius of curvature or directly proportional to the rate of change of direction $\left(\frac{d^2 y}{d x^2}\right)$. In fish-plates of uniform length the bending moments may be considered as being inversely proportional to the mean radius of curvature over a length equal to the length of the fish-plate. Examination of some of the track depression curves obtained in America (2) will show that the spacing of the wheels is often of greater importance than the actual axle load. For instance, between two wheels approximately 5 feet apart, the curves may be comparatively flat with low bending moments in the rail, but with wheels about 9 feet apart the curvature producing a negative bending moment over a

(1) The terms « positive » and « negative » in connection with bending moments are used where tension is produced in the bottom and top flanges respectively.

(2) Progress Report of the Special Committee on Stresses in Railroad Track », published in *Bulletin of the American Railway Engineering Association*, Vol. 19, No. 205, March, 1918.

length equal to the length of the fish-plates may be greater than the reverse curvature over the same length immediately under one wheel. Exceptionally severe negative bending moments may be obtained between the front wheel and the driving wheel of a locomotive or between the bogies of two heavily loaded wagons. In fact with wagons designed to carry very heavy loads bogie wheels, which, by flattening the curve under the load, will decrease the positive bending moment are used. Their effect, however, on the reverse curvature between the bogies is slight, and experience has shown that the maximum negative bending moment is generally greater than the positive.

Length of fish-plates.

The general tendency in modern design is to shorten fish-plates. On some of the older lines in India six-hole plates are used, whereas nowadays only four-hole plates are supplied. Captain Walker (3) of the Federated Malay States Railways, has stated that most of the trouble with rail joints can be traced directly or indirectly to the use of long six-hole angle plates, whereas four-hole flat plates, among other advantages, have exhibited less tendency to bind, give better alignment, easier maintenance, and very much smoother running. A further step in shortening the length will be found in the Joyce pattern fish-plate, which is being employed on some lines. Its effective length is the thick centre portion of 7 inches, which alone is in contact with the fishing planes; the wings lengthen the plate to 18 inches and enable one extra bolt on each side to be fitted, but are not in contact with the rail and do not affect the stiffness of the joint in any way. This follows from the results of experiments by Mr. Lloyd Jones (4), Chief Engineer of the Nizam's Guaranteed State Railway, showing that the stiffness of a joint is independent of the number and of the tightness of the bolts.

The increase in the bending moment with longer plates may be readily understood by studying the attached diagram which represents the depression of a rail between two wheels giving a negative bending moment in

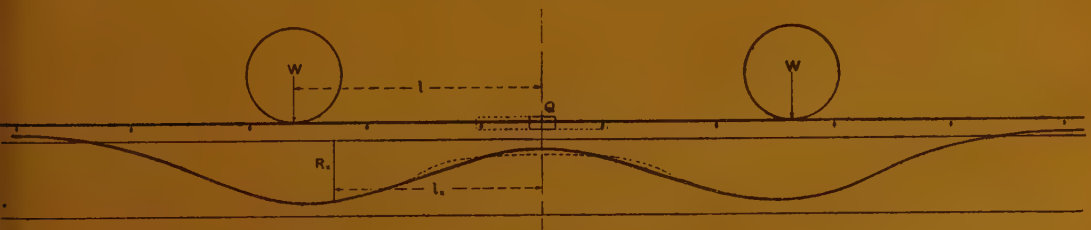


Fig. 20.

the middle. With joints at any point on the curve, the combined moment of inertia of the rail and fish-plate would be greater and therefore the curve would be slightly flattened. The longer and stiffer the fish-plate, the more the natural flexibility of the rail will be destroyed and the bigger will be the stresses to be borne by the fish-plate. This effect is closely analogous to that of a belt spliced with pieces of glass passing over a pulley. Long pieces of glass would break, while, on the other hand, the shorter and more springy the glass the smoother the running. Mathematically the problem is analogous to weights (w) resting on a flexible steel ruler supported throughout its length by a thick pad of rubber, the resulting reaction

(3) *Journal of the Permanent Way Institution*, vol. 41, part 1, page 260. April, 1923.

(4) *Proceedings of the Institution of Civil Engineers*, vol. 182, 1910.

(R) at any point being proportional to the depression. The bending moment (B M) at any point (P) is obtained by the usual equation :

$$\text{BM at P} = \Sigma_{x=o}^{x=\infty}(R_x \times l_x) - \Sigma(W \times l)$$
$$= \Sigma R \times l\,c\,g - \Sigma(W \times l)$$

where l c g is the distance from p of the centre of gravity of the area of depression on one side of p. Where the curve is parallel to the zero line, as in the diagram at Q, the sum of the reactions on one side (Σ R) must equal (Σ W), and for a given load the following equation is obtained :

$$\text{B M at Q} = (W \times l\,c\,g) - (W \times l)$$
$$= W(l\,c\,g - l).$$

That is to say, the bending moment is proportional to the distance of the application of the load from the centre of gravity of the area of depression. With a longer fish-plate at Q the curve will be depressed under Q and raised equivalently between W and Q, the distance from Q of the centre of gravity of the area will be reduced and therefore the negative bending moment will be increased. In the same manner it can be proved that the maximum positive bending moment is increased immediately under the load. If it be desired, therefore, to stiffen the joint it should not be done by lengthening the fish-plates.

For lateral bending stresses on curves the equation is simpler :

$$\text{B M} = \frac{\text{E I}}{\text{Radius of curvature}}$$

With longer plates the mean moment of inertia (I) over a given distance, say 3 feet, is increased and therefore the bending moment is greater, or, for a given bending moment the curve will be flattened over a length equal to the length of the fish-plate, so that the shorter the plate the smoother the running.

Fish-plates, therefore, should be made as short as practicable. As it has been proved (4) that two bolts in a pair of plates are sufficient to ensure rigidity of the joint there should be little necessity for a greater length than 7 to 8 inches. It has been argued that more than one bolt on each side is required to resist creep. Practical experience alone can settle that point, but when both creep and contraction occur the forces coming into play may be enormous, and as the same extension is required to shear one bolt as is required to shear two or more, there is probably little advantage in a larger number.

With shorter plates the tensile and shear stresses would not be increased. The intensity of the pressure between rail and fish-plates would be greater, but could be counteracted by the use of harder steel, which might be employed with greater safety. It is the bending stresses which cause fish-plates to fail, and they would be reduced.

It is not within the province of this article to consider the relative advantages of supported against suspended joints, but it may be said that the former would give smoother running and reduce the intensity of the pressure between the rail and the fish-plate when the joint is immediately under the load, especially if some form of bearing plate were used.

[621 .336 (.73) & 721 .9 (.73)]

4. — Precast concrete arches carry trolley wires.

Figs 21 to 24, pp. 777 and 778.

(*Engineering News-Record.*)

A novel structural feature introduced in the electrification of the Detroit, Toledo & Ironton Railroad at Detroit, Mich., is the use of reinforced-concrete arched bridges or spans to carry the overhead wires, these taking the place of the usual structural steel bridges

or steel poles. This electrification is being applied between Mossy Rock, Mich., and the Fordson terminal at Detroit, a distance of about 17 miles. A series of these arches on a four-track line is shown in figure 21.

The arch spans are built of precast concrete members of H-section. For the normal double-track spans there are two side columns and two arch segments, with a spacing of 33 feet centre to centre of columns and a height of 34 feet above top of rail. Where additional tracks require longer spans, a horizontal spreader beam is placed between the arch segments. The arches are spaced about 300 feet apart. Those used to carry signals, as shown by figure 23, have smooth surfaces for the attachments and have inclosed conduits.

Fig. 21. — Concrete trolley wire arches, Detroit, Toledo & Ironton Railroad.

A plant for manufacturing the concrete units was established at the railroad's Rouge River yard and with a force of 60 men has a daily capacity of 22 members. Reinforcing rods are sandblasted, bent to shape and moved mechanically to platforms where men assemble them in skeletons which are spot-welded together, thus eliminating the use of tie wires. Forms with the reinforcement secured in place are carried by monorail hoists and placed on flat cars which are run to the concreting plant; after standing 24 hours in the yard, the forms are stripped and a coat of cement grout is applied to the concrete. The units are then moved first to a curing oven where they are steamed at 90° to 120° for 24 hours, and then for a similar period to a drying oven of about the same temperature. Small trucks on rails then carry the units to the storage yard, where they are held for at least 18 days, after which locomotive cranes load the units on railroad cars by means of rubber-faced tongs attached to a swing beam on the crane hoist. Columns weigh about 5 1/2 tons and the half-arches about two tons each.

After engineers had staked out the foundations, a work-train crew made the excavations and set the anchor bolts, electric cables and reinforcing. Another crew poured the concrete, which was left to set for 24 hours before removing the forms and then for at least five days before placing the columns. With a train load of columns on one track and a locomotive crane on the other track, the columns were swung into position and set over the projecting anchor bolts. A 2-inch space was left for steel wedges to plumb the column, after which the space was packed with cement grout.

Arch members were handled on a similar train. For an ordinary span, the two members were assembled and bolted together on a car having a working platform, the com-

Fig. 22. — Setting precast column for trolley wire arch.

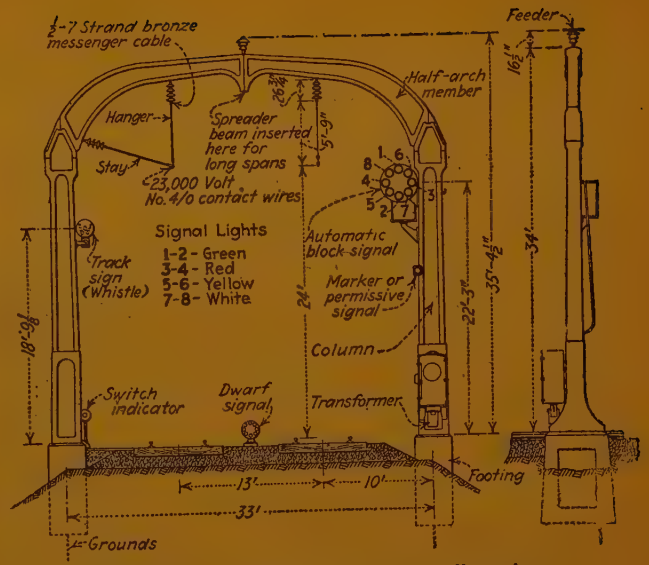


Fig. 23. — Concrete support for trolley wires *showing attachment of track signs and location of block and dwarf signals.*

pleted unit being then set in place by a locomotive crane and bolted to the columns. For long spans having the spreader or extension beam at the middle, one half-arch was set in place on a column, bolted up and supported by a falsework bent. The extension beam was bolted to the other half-arch and this unit was swung into place, while men on the falsework bent bolted the spreader to the first half-arch. Finally, the messenger and trolley wires were strung by a work train having flat cars for reels of wires and box cars on which was a high platform or trestle for the workmen.

Color-position automatic signals are installed : two green lights in a vertical line indicate « proceed »; two yellow lights in a diagonal line, « proceed with caution to next signal »; two red lights in a horizontal line, « stop ». At some points there is a marker lamp placed below the main signal, under control of the train dispatcher and used as a permissive or calling-on signal. When this signal is displayed it shows an amber light and indicates that a second train may pass the red or « stop » signal and proceed cautiously to the next signal.

The concrete arches, electric wiring system and signal system were designed by the engineers of the Detroit, Toledo & Ironton Railroad; and all construction and erection work was done by company forces.

[656 .212.8 (.3)]

5. — Foreign loading gauges.

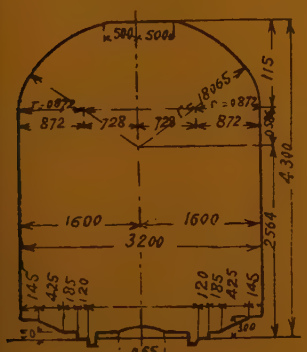
Figs. 25 to 39, pp. 779 to 781.

(*Revue Générale des Chemins de fer.*)

The *Zeitschrift des Vereines Deutscher Ingenieure* has published in different articles the gauges of rolling stock or of permanent way structures which are reproduced below (figs. 25 to 39), all dimensions being given in millimetres.

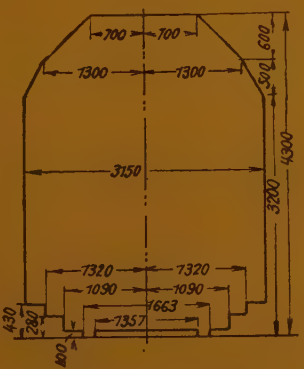
In addition to these gauges the gauge of one of the French railway systems, as well as the international maximum gauge, both to the same scale, are also reproduced for comparison.

Figs. 25 to 39.



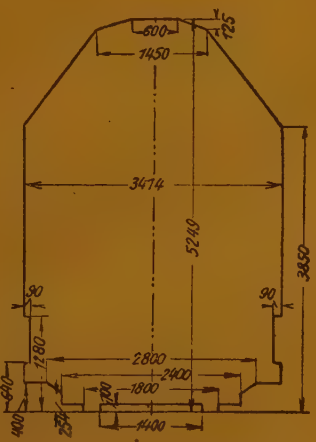
Gabarit P.L.M.

Paris, Lyon, Mediterranean gauge.



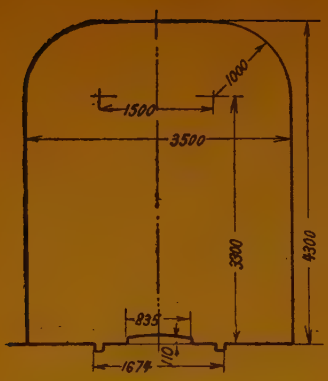
Chemins de fer Danois de l'Etat, à voie de 1m435

Danish State Railways, 4 ft. 8 1/2 in. gauge.



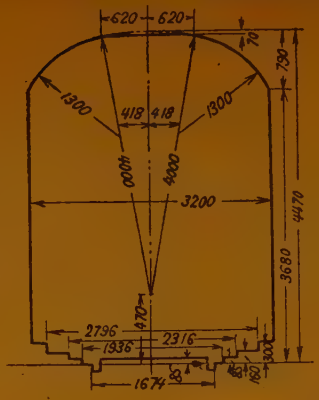
Chemins de fer Russes à voie de 1m524

Russian Railways, 5 ft. gauge.



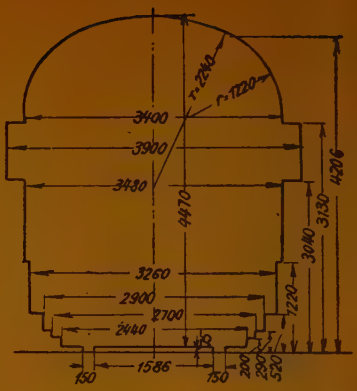
Ch^ins de fer Madrid-Saragosse

Madrid Saragossa Railway.



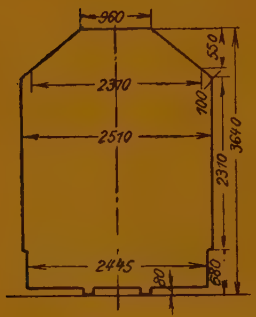
Ch^ins de fer du Nord de l'Espagne

Northern of Spain Railway.



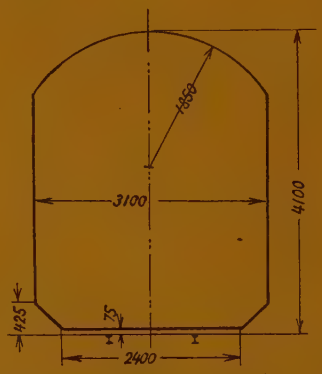
Espagne, voie large

Spain, broad gauge.



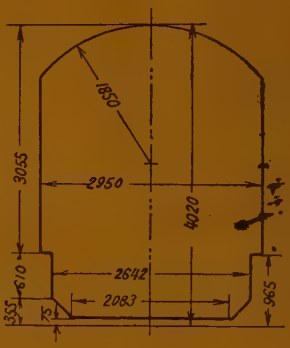
Ch^ins de fer de l'Etat Yougo-Slave, voie de 0m.760

Yugo-Slavian State Railways, 2 ft. 6 in. gauge.



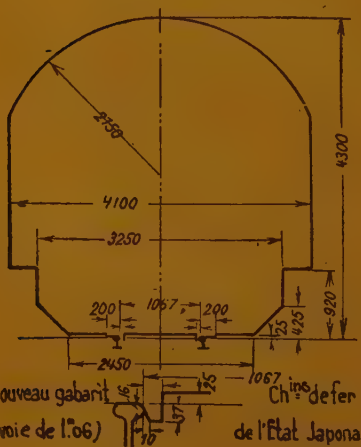
Nouveau gabarit du matériel sur les Ch^ins de fer de l'Etat Japonais

Japanese State Railways, new loading gauge.



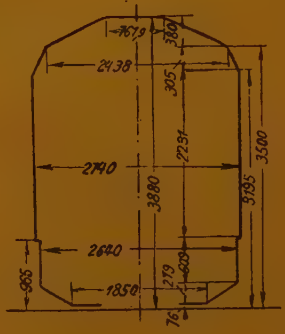
Ancien gabarit du matériel sur les Ch^ins de fer de l'Etat Japonais

Japanese State Railways, old loading gauge.



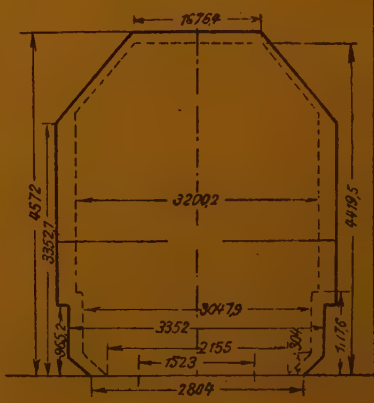
Nouveau gabarit (voie de 1m.06) Ch^ins de fer de l'Etat Japonais

Japanese State Railways, new loading gauge (3 ft. 6 in. gauge).



Ancien gabarit des Ch^ins de fer de l'Etat Japonais (voie de 1m.06)

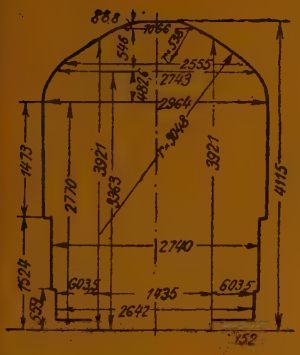
Japanese State Railways, old loading gauge (3 ft. 6 in. gauge).



Chemins de fer Australiens (voie de 1m.435)

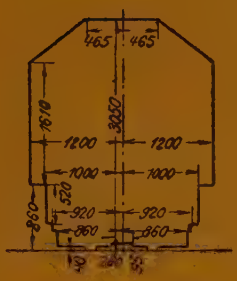
Australian Railways, 4 ft. 8 1/2 in. gauge.

Figs. 25 to 39 (*continued*).



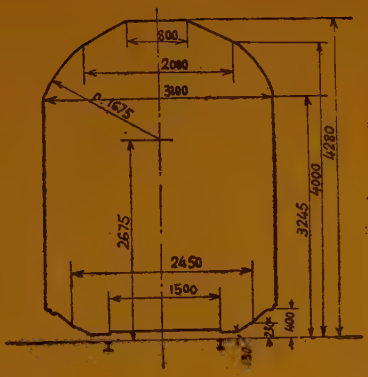
Great Western Railway
Etats-Unis (voie de 1m435)

Great Western Railways, U. S. A.,
4 ft. 8 1/2 in. gauge.



Chins de fer de l'Etat Argentin
(voie de 0m75)

Argentina State Railways,
2 ft. 5 1/2 in. gauge.



Gabarit passe-partout
international

International maximum loading
gauge.

[625 .216 (.52)]

6. — Change of couplings on the Japanese Railways.

In the December 1925 *Bulletin*, p. 2579, particulars were given of the change over from ordinary to automatic couplings on the Japanese Railways.

Readers will recollect that the change over was completed in a single day. The Japanese Authorities thereby avoided the transition stage which is one of the difficulties of this question.

We are able to-day to publish a note from the Japanese Government giving further details of this notable achievement.

Shortly after the nationalisation of the railways in Japan, it was felt that the screw and link couplings, hitherto used, should be changed for an automatic type. It was realised that such a step would take a considerable time, and it was not until 1918 that the Japanese Government Railways definitely decided to make the change. The preparatory work necessary was however, begun and went on steadily until this stage was completed in the spring of 1925. It was then decided to change the couplings in July of that year, and the work was carried out with success.

The Japanese Railways had used screw and link couplings since the construction of the first line in Japan by English engineers in the year 1872. Its use was universal, with the exception of the Sapporo Division (in Hokkaido), where an automatic coupling of an American type was adopted more than fifteen years ago. The railways in Formosa, Korea and South Manchuria had adopted a similar type of automatic coupling from their inception. On the railways of China, the same type was also in use. With the change on the Japanese Government Railways, the couplings of the railways in the Far East are now of one standard, with the exception of those used on the Russian section.

The Japanese Government did not hesitate in adopting the American type of automatic coupler without considering the adoption of a new design as has often been suggested in Europe. The question arose as to which of

the American types should be used. The American standard D coupling was thought to be too heavy for the Japanese Railways, and it was questioned whether the so called 300 lb. type was strong enough. From the experience obtained on the Sapporo Division, it was felt that the Sharon type would prove satisfactory. The Alliance coupling was afterwards introduced and proved to be equally good. These two types of coupling were adopted as the provisional standard, and the necessary details purchased from America and fitted to almost all the rolling stock. Recently, a Japanese interchangeable design has been introduced, and it is thought will be extensively used. The draft gear is of a very simple type and consists of front and rear followers with a draft spring between them and a coupler yoke to hold them in position. Such a type has been considered good enough for the present traffic conditions existing in Japan, but sooner or later it will be necessary to improve the draft gear.

The preparatory work was carried out in three stages, as follows : The first stage was the reconstruction of the underframe where necessary, removing the centre sills further apart, and attaching a pair of follower guides to the inner surface of the centre sills. The wooden centre sills, which are still used on about one-third of the freight cars, are not strong enough to fit the automatic coupling to, and therefore they had to be strengthened by attaching flat bars and tie rods or angles. The centre part of the headstock was cut down to make a recess for the coupler, and angles were attached to the top and bottom ends of the recess to constitute the upper and lower shank guides. After completing this first stage of the preparatory work, the drawbar in use was arranged with a special washer to receive the drawbar spring. This reconstruction was carried out on all passenger and freight cars. In the case of the locomotive, a pivoted coupling was used, the pocket of which was bolted to the buffer beam, so that the reconstruction in this case was simpler. At the rear end of the tenders, the standard car coupling with its draft gear was used.

The second stage of the preparatory work was to temporarily hang the coupling with the draft gear under the centre sills, together with the uncoupling lever. This work was only carried out for the freight cars. There were, however, several types of freight cars whose construction did not permit of this work being done. These were treated as special cars, and special arrangements made for them when the change of coupling took place.

In the case of locomotives and passenger cars, it is known that they returned to home stations, as set out on the timetable diagram. It was easy therefore, knowing where they would be situated, to arrange for the change of their couplings. What was done was to legislate for the exact material required to be provided at these home stations. The case of freight cars was, however, quite different. It was questionable whether it would be possible to have the exact amount of material for changing a certain number of freight cars which could be allocated to a certain station with the certainty that the correct number of freight cars would be available at the time the change was to take place. A considerable number of men would have been required to distribute such heavy material as the couplings to each freight car at the time when the change was to commence. It is hard work to raise the heavy coupling with a jack, so it was preferable to get rid of such work at the time of the change. It was self evident that the change should take place at one time and at as short a period as possible, and therefore it was of the utmost importance to make the operation as simple as possible so that the labour and time should be reduced to a minimum. There was a number of freight cars to be dealt with, and this was the reason that the second stage of the preparatory work was carried out on them.

The third stage was to test whether the work of the first stage had been carried out properly or not, so that the change of couplings might be effected without trouble. It was feared that the work might not have been correctly carried out, and therefore as the operations were finished, they were rigidly inspected with special gauges, and it will be

appreciated that this was a matter of great importance.

The operations carried out were to take off the coupling of the draft gear, which was hung under the centre sills, and to apply it to the underframe, as was to be done when the actual change took place. The uncoupling lever was examined. The coupling was then taken out and again hung under the centre sills. The side buffers were taken off and put up again. All bolts and nuts which were taken down were lubricated with grease to prevent their becoming rusty. This third stage of the preparatory work proved very effective, not only in discovering defective work, but also in familiarising the employees with the operations.

The tools and appliances used in this third stage were the same as those employed in the actual changing of the couplings. They were devised by different men and were not uniform throughout the divisions, with the exception of two essential tools, *viz.*, the jack for the coupling gear and the spanner for the drawbar nut. These were adopted from competitive designs submitted. The jack was a double threaded screw jack. The minimum height was 1 ft. 3 3/4 in. so that it could be placed under the coupling when hung under the centre sills of a loaded car, whilst its maximum height was 2 ft. 8 1/2 in., so that it was capable of jacking up the coupling to its proper position in the case of an empty car. The spanner was of a special design, because it was intended to unscrew the drawbar nut on the coupling hung under the centre sills. These implements had to be light, easy to handle and cheaply made, because they were for temporary use only.

It was an essential matter to determine the correct number of men who would be required on the work at the date of the change, as some of them might be unskilled labourers who had little experience in the work. Many trials were carried out both in the workshops and in the car inspection depots with a view to ascertaining how much work might be looked for from each man. In one case, a set of two skilled workmen changed the couplings of ten wagons in one day of nine working hours. In another case, two workmen who had only under two months' experience in the freight car shop and had only in practice changed couplings three times, changed the couplings of six wagons in the same time. In addition, in the car inspection depots, arrangements were made with a view of predetermining how the men should be used, and allowing those chosen to acquire the experience of the work so that it might be done accurately and carried out in a certain order.

After a good deal of investigation and experiments in the workshops and car inspection depots, the conclusion was reached, that upon the assumption that all kinds of workmen from the shops would be employed, three and a half freight cars per day could be looked upon as a fair average per man. Having this is mind, workmen of all types were trained for about a year in all workshops and car inspection depots. At first this was done on a rather small scale, but as the day for the change approached, the practice was extended, so that all the workmen had at least one day's experience, although results naturally differed. The arrangement was that all the men in the car inspection depots were to be employed on freight car work, and the remainder of the men on passenger cars. It was decided that the workmen in the running sheds should change the couplings on the locomotives.

The employees to deal with the freight car couplings were divided into gangs, each gang consisting of three to eight workmen according to circumstances. Trials were made in the workshops to find the best size of gang. In some cases it was found that an eight man gang was best, whilst in others a seven man or even a six man gang was preferred. From the point of efficient use of tools and appliances, and minimising the number required for the work, a gang of as many men as possible, up to eight men, was found to be preferable. The actual size of the gang was left to the head of the shop.

The number of employees available for the change of freight car couplings was found to be rather less than that desirable for the com-

pletion of the change for the predetermined number of freight cars in a single day. It was decided that the change should take place on the 17 July, except in the Kyushu district, where it was to be carried out on the 20 July.

In Japan it is very hot in July, but there were certain reasons why it was decided to do this difficult work at this time of the year. The principal reason was the necessity of choosing a time when the freight traffic was not dense, so that the effect on traffic itself should be a minimum. At this time of the year, some of the freight cars could be permanently withdrawn from the service, and the couplings changed either before or after the universal change. In addition, July 15 and 16 are Buddhist Holidays, and therefore it could be safely assumed that the freight traffic would be especially light on the 17 July; also, the days are long in July.

The change of coupling for freight cars was made at one time in order that it would cause as little delay as possible to the traffic. The change of coupling, however, of all passenger cars could not be carried out at one time, the cars in a train being usually treated as one set and seldom connected to those of other trains. The general plan for the date of the coupling change was therefore decided as follows :

The couplings of the passenger cars, which constituted the regular composition of a train, were changed in the period from the 1st to the 10 July, except those at each end of the train. The couplings of spare cars and those under repairs in the workshops were changed in the period from the 11 to the 16 July. The couplings on both ends of the train and on the locomotive were changed on the 16 and 17 July. As previously stated, freight car couplings were generally changed on the 17 July, the general work, however, being carried out in the Kyushu district on the 19 and 20 July.

The changing of the couplings of both ends of the train and of the locomotive was done according to the predetermined schedule, in the short time the locomotive and train were at their terminal station between their coming in from one journey and starting the next one. Thus the passenger service on the 16 and 17 July was carried out as usual. A shunting locomotive was required to haul the cars fitted with either the screw or the automatic coupling, and for this purpose, a special coupling was designed and used. The freight car service was suspended for one complete day, namely, from midnight to midnight, except certain special freight trains for the transport of fish, etc. In some, districts where the number of trains per day was comparatively small and the station yard fairly large, it was found that the change over could be done by suspending a few freight trains. On the main lines, however, it was dangerous to adopt such a procedure, because delay at any station might cause considerable confusion to the whole of the system, and even the passenger service might be seriously affected. The safer way of stopping the whole of the freight service was adopted. After the suspension of the freight service, the cars were concentrated in big stations which had been selected as the points for changing the couplings in the course of the night, there being 221 of such stations. Table I gives the particulars concerning the change as regards freight cars.

It was very difficult to allot the predetermined number of cars to a station. For this purpose a special investigation was made for 10 days to ascertain the number of freight cars on hand at various points, and the result of the car allotment on the 17 July proved in every way satisfactory. The cars at the changing stations were arranged at a regular distance, about 3 ft. 11 1/4 in. apart from buffer to buffer. This lay-out was completed by 5 o'clock in the morning, and the actual work of changing commenced at the same time, and was finished by 7 o'clock in the evening. Actually the work was begun in some places as early as 4 o'clock, whilst in certain stations a portion was carried out on the previous day, and the whole operation went on satisfactorily. In the Sendai Division, all the work was completed before noon. In the Kobe Division it was finished at 4.30; in the Tokio Division at 5.30; in the Moji

Division (Sanyo district) at 6.30, and in the Nagoya Division at 8.

It was feared that there might still be many cars of which the couplings had not been changed owing to faulty preparatory work, although every effort was made to minimise the number of such cars by carrying out the testing and inspection of the third stage of the preparatory work. In order to cope with these several special gangs were allotted to the principal stations. These proved very useful, and the number of cars which had to be sent to the workshops was only about 10.

The most important matter with regard to the change was the inspection of the work after it was done. For this purpose the foremen of the workshops were carefully instructed in the necessary inspection and served as inspectors, as well as foremen of the work itself.

The old couplings and buffers were loaded into empty cars which were conveniently placed for the purpose, and which were immediately moved so that the work of the yard should not be hampered by the couplers and buffers lying by. The material was sent to the workshops to be sorted out for the purpose of renovation, etc.

It was feared that a number of workmen might be injured, because most of them were not accustomed to the work, which was of a fairly difficult character. The result, however, was very satisfactory, for although a number of injuries did take place, they were only of a slight character.

The total expenditure of the change of the couplings amounted to about 25 000 000 yen, details being given in table II.

The private railways whose freight cars are run over the lines of the Government Railways changed their couplings at the same time and in the same way. The Government Railways paid about 259 yen per car as subsidy.

The organisation of the work was as follows :

All the plans of the preparatory work were made in the Mechanical Department of the Ministry of Railways, and the work carried out in the railway workshops. The change over was organised by a committee presided over by the Deputy Minister. This committee only drew up a general plan, a detailed plan being prepared by the committee nominated for each Divisional Office. The divisional committees consisted of the Chief of Operation as Chairman, the Chief of the Mechanical Section, and the Chief of the Transportation Section acting as Vice-Chairmen. The rest of the committee consisted of engineers, works managers, chiefs of car distribution, etc. When the divisional plans were completed and forwarded, it became necessary to decide on the factors which should be common on all divisions. To carry this out, an executive committee was appointed by the Ministerial committee, and was presided over by the Chief of the Operation Section. This had called together the divisional committees and held many joint meetings, in which the necessary arrangements were made. The organisation was not identical in all the divisions, although very similar. As an example, the organisation of the Tokio division may be taken.

The headquarters were situated in the Divisional Office. There were ten districts, the chief of each district being the head of the District Traffic Office or the Works Manager. Under the control of the district headquarters were nineteen local centres, and under these were fifty-four groups, the heads of which were usually the assistant engineer from the workshops. One group was allocated to each changing station, with the exception of the four large stations, to which two groups were allotted. Each group was still further subdivided into parties of men each under the foremen. These were further sub-divided into gangs which consisted of from five to eight workmen according to circumstances. In addition there were nineteen special gangs and eleven relief gangs.

At each changing station there was a number of men under the charge of the stationmaster. The function of these was to arrange the cars as required, to prepare lodgings and meals for the men, and to dispose of the old couplings and buffers, etc. These men were

TABLE I. — **Number of freight cars, workmen and coupler-changing stations.**

DIVISION.		*Tokyo.*	*Nagoya.*	*Kobe.*	*Moji.*		*Sendai.*	Total.
					Sanyo district.	*Kyushu district.*		
Pre-determined allotment of cars. .		15 000	10 000	10 000	2 500	8 650	6 500	52 650
Ditto for the July 17th. (20th) . . .		12 705	8 300	7 849	1 850	7 162	4 800	42 637
Actual number of freight cars of which the couplers were changed on 17 (20) July.		12 523	8 377	7 607	1 842	7 151	4 170	41 670
Number of workmen on 17 and 20.	Workshop workers. .	3 183	2 135	1 507	452	1 502	1 032	9 812
	Car inspectors	823	274	720	40	300	358	2 694
	Total	4 006	2 409	2 224	492	1 802	1 570	2 506
Number of coupler-changing stations.		50	54	39	8	45	25	221

TABLE II.

—	Locomotives.		Passenger Cars.		Freight Cars.		Total Expense.
	Number	Expense.	Number.	Expense.	Number.	Expense.	
Preparatory work of 1st. stage	2 529	645 993	6 385	2 583 776	41 667	9 797 681	13 027 450
Materials, including couplers and their erection .	3 344	686 267	9 057	1 564 985	51 541	8 181 902	10 434 154
Preparatory work of 2nd stage	..	...	...	...	...	578 717	578 717
Change of couplers at one time	...	...	...	...	..	...	527 600
Total. . .	...	...	...	...	...	..	24 567 921

yardmen and employees other than shopmen. The co-operation between the whole of the organisation was satisfactory.

In this manner the coupling problem of the Japanese Railways was solved. The fact that the Japanese railway lines are under one control, and that there is no through traffic of cars outside the islands of Japan, considerably influenced the Government to adopt the automatic coupling. The work of the change nevertheless was a fairly large undertaking, and even an American expert did not believe that it could be completed in one day. This was, however, accomplished. The improvement of the couplings will undoubtedly aid the development of traffic, and also enhance to a large degree the safety of the employees. To couple a car under the old system, especially in Japan, was a very dangerous task, because the distance between the buffers and coupler from centre to centre was only two feet. Statistics reveal the following :

TABLE III. — **Number of injuries and deaths.**

YEAR.	DIVISION.	In the switching work incl. coupling work.			Coupling work only.	
1922	*Tokyo*	Screw and link coupling.	158	559	69	227
	Nagoya	— — —	116		61	
	Kobe	— —	117		23	
	Moji	— — —	85		33	
	Sendai	— — —	83		41	
	Sapporo	Automatic	41		6	
1923	*Tokyo*	Screw and link coupling.	177	599	74	204
	Nagoya	— — —	97		30	
	Kobe	— — —	134		26	
	Moji	— — —	114		49	
	Sendai	— — —	77		25	
	Sapporo	Automatic	27		0	

It is hoped that the couplings of the European railways will be changed in accordance with the desire of European employees, though there are undoubtedly more difficulties to be overcome than in Japan.

[621 .132.8 (.68)]

7. — Garratt locomotives for the Rhodesia Railways.

Figs. 40 to 43, pp. 788 to 790.

(*The Railway Engineer.*)

The locomotive illustrated herewith is one of twelve Garratt locomotives recently completed by Beyer, Peacock & Co. Ltd., Manchester, for service on the Rhodesia Railways, and is of special interest as being fitted with Lentz patent poppet valves, one other engine

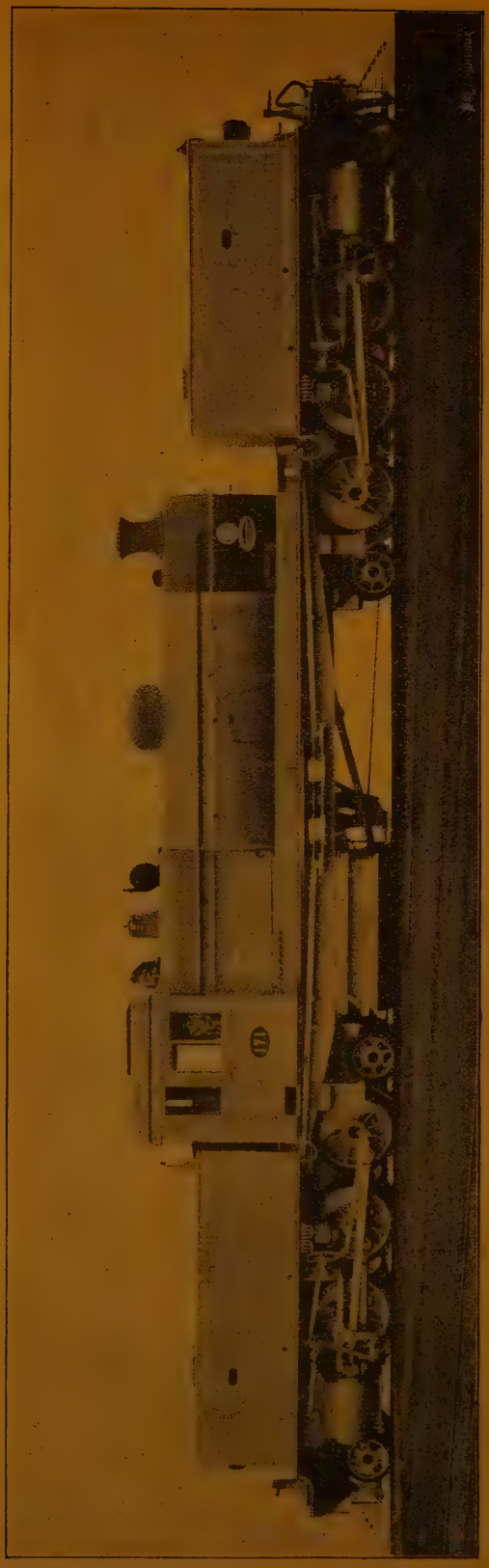


Fig. 40. — Garratt locomotive, 2-6-2 + 2-6-2 type, for the Rhodesia Railways. Built by Beyer, Peacock & Co. Ltd.

comprised in the order being similarly equipped. The locomotives conform generally to the usual Garratt principle, and the following is a description of the engines which are the first of their type to be used on the Rhodesia Railways.

The boilers have Belpaire fireboxes and are fitted with the Superheater Company's type A equipment. They have a diameter of 6 feet outside and the barrel portion is 11 ft. 7 in. long. The outside firebox is 7 ft. 3 in. long and rocking firebars are fitted. The ashpans are of the hopper pattern having side and bottom cleaning doors. There are 184 2 inch and 32 flues 5 1/4 inch diameter, and the elements are 1 3/8 inch diameter outside and the length between the tube plates is 12 feet. The working steam pressure is 180 lb. per square inch.

The power units have the 2-6-2 wheel formation and driving wheels 4 feet diameter, the carrying wheels all being 2 ft. 4 1/2 in. The leading trucks in each direction of running are of the radial arm type, and the inner axles are fitted with Cartazzi sliding top axle-boxes.

Spring compensation is provided, the arrangement being such that the leading trucks are equalised with the leading coupled axles and the intermediate and driving axles are likewise connected with the inner carrying axles. The third coupled axle takes the drive through connecting rods 8 ft. 7 in. long between centres.

The slide bars are of the single bar type, and the crank pin ends are bushed solid as are also the coupling rod pin bearings. Walschaerts valve motion is used and a steam reversing gear is employed.

The cylinders for the engine, whether fitted with piston or poppet valves, are interchangeable. This has been made possible by the fact that the piston valve chests are separate from the cylinders to which they are studded in exactly the same manner as the poppet valve chests. By the adoption of the above arrangement not only have interchangeable cylinder castings been obtained but also the same steam and exhaust pipe connections. The entire valve motion up to and including the pendulum links is alike for all engines, the only difference being that in the case of the piston

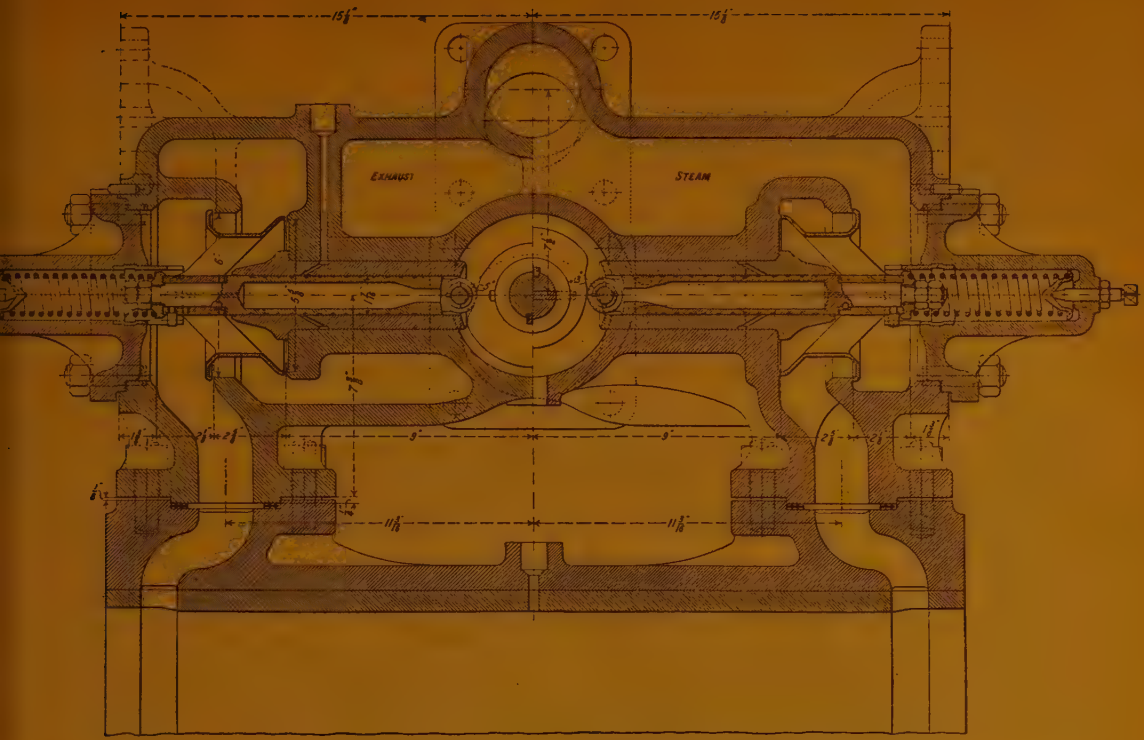


Fig 41. — Longitudinal section showing arrangement of Lentz valve box.

Fig. 42. — View of the valve box and valve motion.

valve engine the usual valve stem is employed, coupled to the combining levers in the ordinary way, whilst in the case of those engines fitted with the Lentz valves a valve connecting link joining the pendulum and the camshaft rocker arm is employed.

The arrangement of the Lentz valves as applied to these locomotives is shown by figures 41 and 42, the former being a longitudinal section whilst the latter is a transverse section through the camshaft, and figure 42 is a view of the valve box and valve motion, from which it will be seen how the Lentz valve gear is connected to the Walschaert motion through the intervention of a pendulum which supports the combining link. Reversal and the variation of

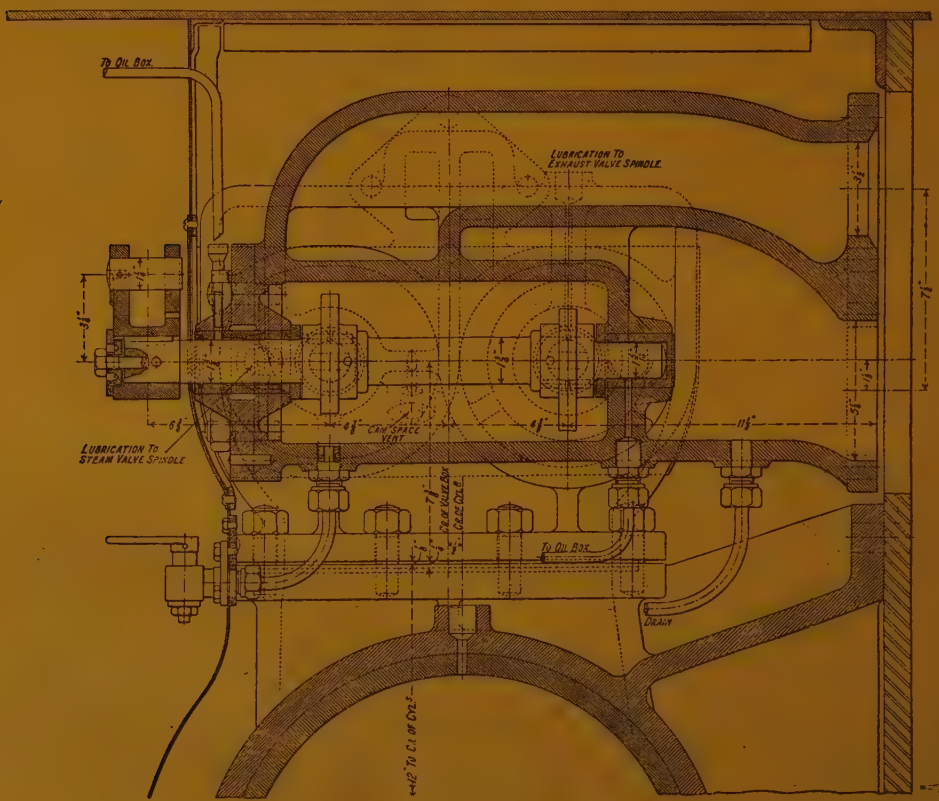


Fig. 43. — Transverse section through camshaft.

the admission period is controlled in the same manner as with piston valves, the swing of the camshaft rocking arms which governs the valve openings being dependent upon the position of the link block. There are in all four double beat valves, of forged steel, 1/8 inch in thickness in each valve casing; they have an inside diameter of 6 inches for the upper seating and 5 5/8 inches for the lower. The steam tightness of Lentz double beat valves is due largely to their specially designed shape, the feature of importance in this being the comparative flexibility of the upper face which allows of its being pressed upon its seating by the steam pressure. This, together with the cam control, is responsible for the satis-

factory operation of the valves in high speed working. The two outer valves control admission and the inner two the exhaust.

Special alloy steel is used for the valve spindles and cams, all of which are hardened on their working surfaces. The rollers and pins are also hardened. Control springs are fitted for each valve; they have an initial compression of 3/4 inch, transmitting a load equal to 66 lb. when the valves are closed. It may here be mentioned that the valves are lifted from and let down upon their seats by the action of the cams, and that the spindles are in contact with the cams till the valves have actually closed. The main object of the springs is to control the valve action when the engine is running with steam off. With steam on, the closing of the valves is ensured by the out-of-balance pressure due to the difference to the inner and outer diameters and to the area of the spindles.

Lubrication of the valve spindles is effected by feeding oil under pressure through the passageways shown. This has also the effect of assisting the labyrinth form of packing provided to keep the spindles steam-tight in the bushings. The valve casings are of cylinder metal, as are also the covers and spindle bushes. The camshafts are of mild steel and run in bronze bushes.

The valve lead is 5/64 inch, and the cut-off in full gear is 80 %. The maximum lift of the steam valves is 1/2 inch, and that of the exhaust is 5/8 inch.

The special fittings provided include Wakefield's « Eureka » lubricators for the pistons and piston valves, or, alternatively, for the valve spindles for Lentz valves.

Lambert wet sanding gear is fitted to the front and rear of each group of coupled wheels, and the vacuum-brake apparatus is fitted for use on the train, and both the steam and hand brakes are applied to the coupled wheels of the locomotives. The superheater header, saturated steam side, is fitted with the Gresley automatic air valve, and, in addition, each steam chest of the engine has two Hendrie bypass valves. Principal particulars of the locomotives are as follow :

Cylinders	16 by 24 inches.
Wheels, driving diameter	4 feet.
— bogie and carrying	2 ft. 4 1/2 in.
Steam pressure	180 lb.
Rated tractive effort (75 % boiler pressure)	34 560 lb.
Heating surfaces :	
Tubes and flues	1 676 sq. feet.
Firebox	164 —
Superheater (steam side)	380 —
Total combined	2 220 sq. feet.
Weight on drivers	77 tons 11 cwt.
Weight, total engine (in working order)	122 tons 3 cwt.
Coal space	7 tons.
Water capacity	4 350 gallons.

The maximum axle load is 13 tons.

The engines have been built under the supervision of Sir Douglas Fox & Partners, consulting engineers, Westminster.

[625 .258 (.73) & 656 .259 (.73)]

8. — The Union electro-pneumatic car retarder system.

Figs. 44 to 48, pp. 792 and 794.

(*Railway Age.*)

An electro-pneumatic car retarder system has been placed on the market by the Union Switch & Signal Company, and is now being installed on a new 69-track unit of the Markham gravity classification yard of the Illinois Central at Harvey, Ill., near Chicago. The car retarder system as invented and developed by officers of the Indiana Harbor Belt at the Gibson, Ind., yard was described in the *Railway Age* of 15 November 1924 and 9 May

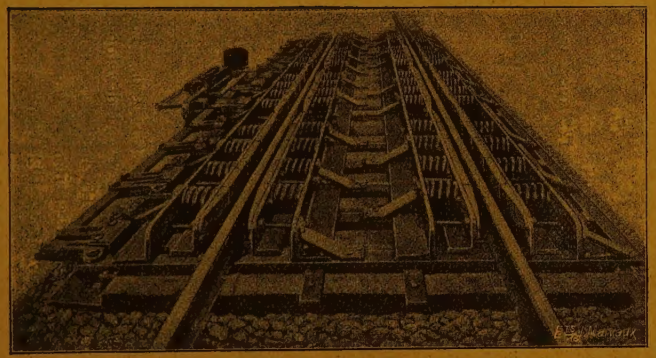


Fig. 44. — Union electro-pneumatic mechanism adapted to operate car retarder arrangement.

Fig. 45. — Electro-pneumatic direct acting switch throwing mechanism.

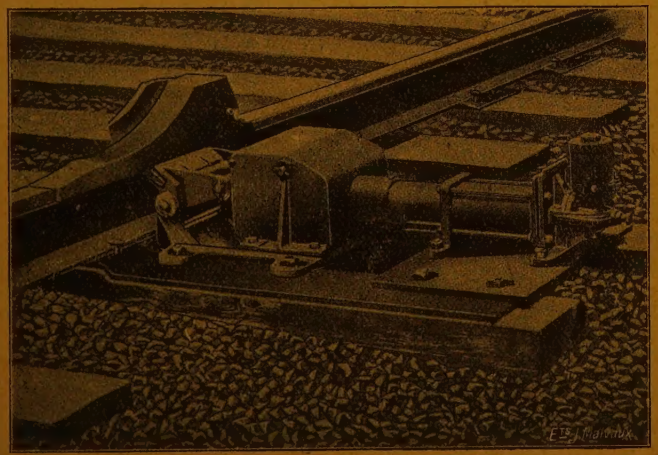


Fig. 46. — Skate mechanism showing skate in place on the rail.

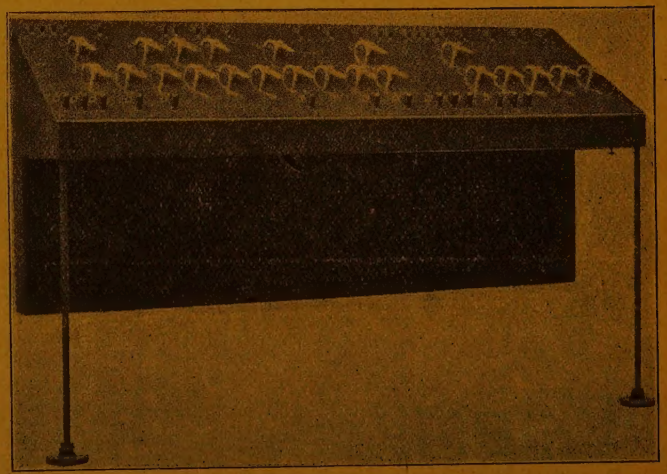


Fig. 47. — Each tower contains a control board for the control of switches, retarders and skates.

1925 (1). Since that time the Union Switch & Signal Company, together with its associate, the Westinghouse Air Brake Company, has, by an agreement with the inventors, continued the development of the electro-pneumatic car retarder system and in doing so has incorporated many of the control features of its electro-pneumatic interlocking.

After making a series of tests to determine the operating characteristics of the car retarder arrangements, the Union Company adapted its standard electro-pneumatic switch machine for the operation of the car retarder. The brake shoes of the car retarder are forced against the inside and outside faces of the car wheels by compressed air acting on a piston, which through levers, transmits the force to the brake shoes. The application and release of this air, and thereby the operation of the retarder, are controlled electrically by means of three control valves, each including a magnet with an air valve. These electro-magnetic air valves are of a design similar to those used extensively on the Union system of electro-pneumatic interlocking. One valve controls the admission of air, one the exhaust and one the release. A pressure controller is provided, by means of which the results described below are obtained.

This control apparatus is so constructed that various pressures may be applied to the operating cylinder, thus varying the pressure exerted by the retarder, so that by using these different pressures, the cars of different weights and running at different speeds are controlled as desired.

The moving of the control lever to any one of the various contacts corresponding to the pressure desired, completes the control circuit, thus energizing the control magnet which results in the admission of air to the operating cylinder, forcing its piston out and the retarder shoes are then in position to exert pressure against the car wheels. The pressure in the operating cylinder builds up almost instantaneously until it reaches the pressure corresponding to the contact made by the control lever and at this point the pressure controller contact opens and no more air is admitted to the operating cylinder.

If the operator finds that he is not using sufficient pressure he moves the control lever to the contact corresponding to the higher pressure, when the above operation is immediately repeated, except that the pressure builds up from the pressure formerly obtained, instead of from zero. This « no loss » of pressure is assured by the exhaust magnet always being energized when the control lever is in position to establish pressure in the operating cylinder.

If the operator finds that he is using too much pressure he has two courses open. He can release the apparatus entirely by moving the control lever to establish contact with the brake release, in which case the exhaust magnet is de-energized, exhausting the air from the operating side of the piston. At the same time the release magnet is energized, admitting the air to the release side of the piston and forcing it back. If he does not desire to release the apparatus entirely, he can push the exhaust button in the control lever, which thus de-energizes the exhaust magnet and exhausts the air from the operating side of the piston, but only for as long a period as he holds the exhaust button open. When he releases the exhaust button, the air immediately builds up again in the operating cylinder to the pressure corresponding to the contact made by the control lever. The advantages of the quick release obtained by releasing pneumatically instead of using a spring, as in the car brake cylinder, are obvious.

The skate mechanism, as manufactured by the Union Company, is simply a small pneumatic cylinder, the piston rod of which is connected to a series of levers, so that when the piston rod is forced out the skate is placed on the rail, and when forced back the skate is removed from the rail, provided a car has not passed in the meantime. An electro-magnet controls the admission of air to this cylinder; when energized, air is admitted to the cylinder, and when de-energized it is exhausted to

(1) See *Bulletin of the Railway Congress*, number of January 1926, p. 11.

atmosphere. The forcing back of the piston is caused by a spring and the weight of the skate itself.

The direct acting electro-pneumatic switch mechanism being furnished by the Union Company for the operation of switches in classification yards consists of a small pneumatic cylinder, the piston rod of which is connected directly to the throw rod of the switch; when the piston is out the switch is in one position, and when the piston is in, the switch is in the other position. The air for this cylinder is controlled by two electro-magnets, one of which admits air to one end of the cylinder when energized, and exhausts it when de-energized. The second electro-magnet valve admits and exhausts air to the other end of the cylinder in the same way. Due to the arrangement of the control lever in the tower, only one magnet can be energized at a time, and, therefore, air is always forcing the switch to stay in the position.

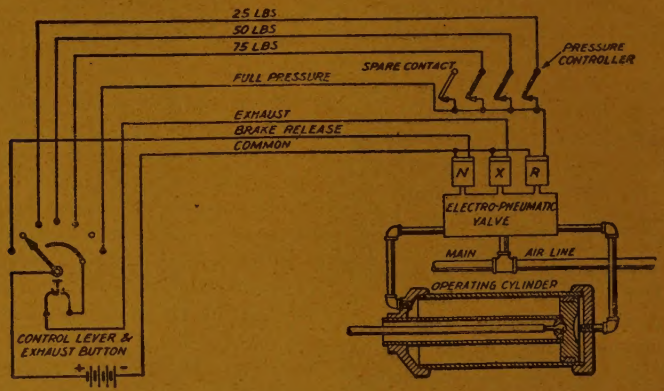


Fig. 48. — Control circuit for operation of electro-pneumatic car retarder system.

All of this apparatus is controlled from central towers placed about the yard. Each tower controls certain retarders, switches and skates, for which a control board of an entirely new design is provided. The control levers for the switches and skate mechanisms are simply two-position switches, so arranged that each position is positive. The retarder control levers require more positions — one for release, one for normal (everything de-energized), and one of the pressures used. These levers are provided with springs and dogs so that each position is positive. The entire board is compact and accessible and so designed that the operator may sit or stand before it, and at the same time see over the top of the board the tracks he is controlling. All of this apparatus uses six-volt, direct current energy, supplied by storage battery, for the control mechanism.